THERMAL POLLUTION—1968

(Part 4)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
IR AND WATER POLLUTION

OF THE

MITTEE ON PUBLIC WORKS
NITED STATES SENATE

NINETIETH CONGRESS

SECOND SESSION

ON

THE EXTENT TO WHICH ENVIRONMENTAL FACTORS ARE CONSIDERED IN SELECTING POWERPLANT SITES WITH PARTICULAR EMPHASIS ON THE ECOLOGICAL EFFECTS OF THE DISCHARGE OF WASTE HEAT INTO RIVERS, LAKES, ESTUARIES, AND COASTAL WATERS

Appendix 2

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STATEMENTS OF IVAN BLOCH, INDUSTRIAL CONSULTANT, PORTLAND, OREG.

IVAN BLOCH & ASSOCIATES,
Portland, Oreg., December 11, 1967.

Hon. EDMUND S. MUSKIE,
Senate Office Building,
Washington, D.C.

DEAR SENATOR MUSKIE: By way of introduction I believe I can say without hesitation that I am a good friend of Senators Gruening and Bartlett of Alaska, having worked with them on developmental matters over a number of years. I am enclosing copy of a paper I delivered in Alaska earlier this year, in which I raise some questions regarding the headlong rush in the United States toward large nuclear power plants. My comments on the subject begin on page 27 through 32. In short, I feel that the nuclear power enthusiasts are forcing the nation into irreversible programs in which there are serious unresolved questions as to safety, pollution, and adequacy of fuel resources. In this regard, I enclose copy of a telegram I sent on November 30, 1967 to Bonneville Administrator Richmond on the occasion of the annual meeting of the Bonneville Regional Advisory Council of which I am a member but which meeting I was unable to attend due to my being in Washington, D.C. I had hoped to establish contact with your office while in Washington, during which time I was on the Advisory Panel of the U.S. Office of Water Resources Research. Unfortunately, I was unable to reach your administrative assistant.

I would very much like to have your office send me whatever material you may have on hand regarding the growing and specific concern on nuclear energy proliferation. It is my understanding that you are going to hold hearings in the near future. I would appreciate being advised as to "where and when", and what kind of testimony you will be seeking.

Looking forward to hearing from you,

Sincerely yours,

IVAN BLOCH.

[Enclosures]

[Night Letter from Washington, D.C., Nov. 30, 1967]

Mr. H. R. RICHMOND,
Bonneville Regional Advisory Council,
Care of Olympic Hotel, Seattle, Wash.

Regret inability attend meeting. Suggest consideration following. Wonder whether so-called competitive nuclear power costs actual or anticipated. Wonder how realistic estimates uranium sufficiency unless materially higher prices. Suggest combination use cooling towers and pondage. Doubt sufficient consideration serious ecological effect use coastal and estuarine water. Suggest cessation public brainwashing by use words costly or expensive conjunction cooling towers. Believe environment should be protected even with consequent slight increase power price. Urge measured consideration power usage economy to slow down mad rush to nuclear plants when so many grave questions on safety, pollution, fuel reserves yet unresolved. What can council do insure BPA power planning leadership to continue and to include at all times complete multilateral responsiveness all environmental factors. Regards to all.

IVAN BLOCH.

Northern Electric Power Developments for Mining and Electroprocess Industries

(By Ivan Bloch, Industrial Consultant, Before 1967 Alaska A.I.M.E., British Columbia C.I.M.M. Conference, May 23–26, 1967, College, Alaska)

ABSTRACT

The North Pacific Country, viz Alaska, Yukon and Northwest Territories and Northern British Columbia, possesses enormous energy resources. These include great deposits of coal of varying grade, tremendous reserves of oil and natural gas, and sizeable potentials in water-power. To date the use of these energy resources for power production has been very small and usually very high cost. In most instances of mining development, the Diesel power plant has been ubiquitous with local energy resources barely utilized. There have been exceptions where the scale of mining development, its anticipated duration, and juxtaposition to nearby energy resources have been made possible relatively small developments in water-power and coal-fired thermal power plants.

Potentially, it appears that the full use of the North Pacific Country's energy resources may commence within the Century. It will depend most probably on the development of very large hydro and thermal power plants, interconnected and operated by means of high-voltage, high-capacity transmission networks. Such developments will rely heavily for their initiation on the growing needs for electric power in Lower British Columbia and the U.S. Pacific Northwest. However, a concurrent use for major electroprocess industries in the North Country will both stimulate and require massive electric power development. Some of these industries can be expected to locate in the relative vicinity of principal mineral reserves in order to facilitate shipment of high-value materials. Other industries will make use of new power supplies at tide-water for transportation of their products to various points in the Pacific Basin area.

Inter-regional power planning, blending all sources of energy including those from nuclear fission, requires the immediate attention of governments and industry. By joint consideration of most effective sources of energy and transmission, low-cost levels can be reached.

INTRODUCTORY

It is a commonly reiterated fact that the economic development of the North Pacific Country will be dependent on the favorable interplay of the value of its resources at the market, the costs of transport from mine to market, the costs of labor and management, and the cost of electric power. This is no different than for any resource anywhere else in the world. Obviously, any reduction in the cost of any parameter is highly desirable.

The cost of power in mining is important but it is not the most critical of all parameters. The supply factor, more frequently than not, is more significant. To the extent electric power can be made available at reasonable cost in such supply as to make its use feasible in all facets of a mining operation, it will be a positive factor in the total equation. Cost levels may very well control the degree to which a mining operation is electrified.

On the other hand, processing of minerals, especially the metallics, can involve very large quantities of electric power per unit of end-material. See Table 1 "Electroproducts, Raw Materials, Power Requirements and Characteristics". It is in this phase of the rendition of mineral values that both supply and cost become a controlling factor. If electric power is available, close to the resource in adequate quantities and at a reasonable price, it may assist considerably in cutting down the overall cost of transport from mine to eventual point of use. It might make feasible the exploitation of a low-value mineral reserve which otherwise would remain dormant for many years.

As of the present time, the North Pacific Country (Alaska, Yukon and Northwest Territories, and Northern British Columbia) is deficient in developed electric power supplies. Mining operations, with few exceptions, rely on ubiquitous Diesel-electric power plant. There are, as yet, no COMINCOS where electric power in abundant supply at very low cost can spawn magnificent electroprocessing complexes for numerous mineral materials. Yet, even a casual examination of information on the energy resources of the North Pacific Country shows that these exist in very substantial untapped reserves, whether in water power, natural gas, petroleum or coal. Here and there, some use is being made of these reserves for electric power production but it is minimal and very restricted.

The purpose of this discussion is not so much to re-examine electric power potentials as it has been done ably on numerous recent occasion, but to re-consider them in the light of major developments in regional power development. It is only during the last half of the decade that the North American Continent has made a huge jump forward toward integration of continental power supplies and markets by means of long-distance, very high-voltage, very high-capacity transmission networks. Suddenly, we see some new horizons, not dimly but as actualities under operation and construction. We also see that regional and national boundaries no longer present insoluble problems but that cooperative and collaborative efforts are profitable in every sense of the word.

This brief analysis will delineate even though very roughly the location and apparent magnitude of the energy resources basic to electric power production. It will delve into a few basic principles of costs for hydro and thermal generation. It will review in perspective something on the transmission of large blocks of electric power. Finally, some observations will be made on the kinds of organizational mechanisms which might be employed to get "the show on the road."

BASIC ENERGY RESOURCES OF THE NORTH PACIFIC COUNTRY

Water Power

The North Pacific Country possesses numerous major river systems which are potential sources of hydroelectric power. It also has many lakes the elevation of which makes possible diversion through power plant turbines. Yet, the popular mind conjurs a vision of solidly-frozen streams and lakes which, obviously, would preclude electric power production. Here and there, this concept is thawed out by actual example of great northern hydroelectric projects such as Shipshaw, Hamilton Falls in northeastern Canada not to mention those of the Soviet Union. As a matter of fact, the National Geographic magazine recently dwelt at length on the Bratsk River project in Central Siberia and the tremendous economic development it has made possible.

TABLE 1.—ELECTROPRODUCTS, RAW MATERIALS, POWER REQUIREMENTS AND CHARACTERISTICS [1]

Product	Process and raw materials	Kilowatt-hours per pound [2]	Kilowatt-hours per ton	Approximate kilowatt capacity per ton	Approximate load factor (percent)
Alumina, fused	Electric furnace; alumina, bauxite.	1.0–1.5	2,000–3,000	0.3 to 0.4	90+
Aluminum	Fused electrolyte; alumina bauxite.	6.5–9.0	13,000–18,000	1.5 to 1.9	99
Caustic soda	Electrolytic; salt and brine (see Chlorine).				
Cadmium	Electrolytic; zinc plant flue dust and slimes.	0.7 to 0.97	1,400–1,940	0.3	98
Calcium carbide	Electronic furnace; limestone and carbon.	1.4–1.5	2,800–3,000	0.4	95+
Calcium cyanamide	Electric furnace; calcium carbide.	1.1–1.3	2,200–2,600	0.4	95+
Chlorates	Electrolytic; salt brines	2.4–3.0	4,800–6,000	0.5–0.8	95–98+
Chlorine	Electrolytic; salt and brines	1.3–1.7	2,600–3,400	0.24 to 0.36	95–98+
Chromium	Electrolytic; chromium salts and ores.	5.0–8.4	10,000–16,800	1.2 to 2.0	98
Chromic acid	do	2.2	4,400	0.5	98
Cobalt	Electrolytic; cobalt ores	1.2–1.6	2,400–3,200	0.3 to 0.4	98
Deuterium oxide	Electrolytic; water	4.0	8,000	0.9	99
Ferrochromiun	Electric furnace; chromium ore and scrap.	3.5–4.0	7,000–8,000	Average 0.82 [3]	85+
Ferromanganese	Electric furnace; manganese ore and scrap.	2.0–3.5	4,000–7,000		
Ferromolybdenum	Electric furnace; molybdenum ore and scrap.	3.0–4.0	6,000–8,000	Average 0.82 [3]	85+
Ferrosilicon	Electric furnace; quartz and scrap.	2.0–3.5	4,000–7,000		
Ferrotungsten	Electric furnace; tungsten ore and scrap.	3.8	7,600		
Ferrovanadium	Electric furnace; vanadium ore and scrap.	2.3–4.0	4,600–8,000		
Fluorine	Electrolytic; fluorspar ore	2.8–3.0	5,600–6,000	0.6 to 0.7	98+
Graphite	Electric furnace; carbon	1.5–1.7	3,000–3,400	0.4 to 0.5	95
Hydrogen	Electrolytic; water	22.2	44,400	5.0	99+
Hydrogen peroxide	Electrolytic; water, ammonium sulfate, sulfuric acid.	8.0	16,000	1.8	98+
Iron, electric pig	Electric furnace; iron ore, carbon.	1.0–1.2	2,000–2,400	0.3 to 0.4	85
Lithium	Fused electrolyte; lithium ore and salts.	15.6–18.2	31,200–36,400	3.6 to 4.2	98+
Manganese	Electrolytic; manganese ore	5.0–5.3	10,000–10,600	1.2 to 1.3	98
Manganese dioxide	do	1.2–1.5	2,400–3,000	0.3 to 0.4	95
Magnesium	Fused electrolyte; salt brines	11.2	22,400	1.9 to 2.3	98+
Mercuric oxide	Electrolytic; mercury ore	2.0	4,000	0.5	98
Nickel	Electrolytic; nickel ore	1.1	2,200	0.3	98+
Oxygen	Electrolytic; water	1.38	2,760	0.4	99+
Perborates	Electrolytic; boron salts	2.7–3.0	5,400–6,000	0.6–0.7	98
Perchlorates	Electrolytic; salt brines	1.5–1.9	3,000–3,800	0.4–0.5	98
Perchloric acid	Electrolytic; salt brines	11.8	23,600	2.7	98
Persulfates	Electrolytic; ammonium sulfate	1.0	2,000	0.3	98
Phosphorus	Electric furnace; phosphate rock, silica and carbon.	4.0–5.5	8,000–11,000	1.5	98
Potassium hydroxide	Electrolytic; potassium salts	1.0–1.2	2,000–2,400	0.3 to 0.4	98
Sodium	Fused electrolyte; salt	5.2	10,400	1.2	95
Sodium sulfate	Electrolytic; salt brine	1.4–2.7	2,800–5,400	0.3–0.6	98
Silicon	Electric furnace; silica and carbon.	5.0–6.0	10,000–12,000	1.2 to 1.5	90
Silicomanganese	Electric furnace; managnese ore.	2.0–3.0	4,000–6,000	0.5 to 0.7	85
Silicon carbide	Electric furnace; silica and carbon.	3.5–4.1	7,000–8,200	1.0 to 1.2	90+
Titanium	Reduction by magnesium; titanium ore.	15.0–18.5 [4]	30,000–37,000	4.4 to 4.6	95+
Zinc	Electrolytic; zinc ore	1.4–1.6	2,800–3,200	0.3 to 0.4	98
Zirconium	Reduction by magnesium; zirconium ore.	15.0–20.0 [4]	30,000–40,000	4.4 to 4.6	95+

[1] Source: Ivan Bloch & Associates files; Mantell, C. L. "Electrochemical Engineering" McGraw Hill Book Co., Inc., 1960.
[2] Only electroproducts requiring 1 or more kilowatt-hour per pound included.
[3] Approximate U.S. average for all ferroalloys.
[4] Including magnesium and chlorine requirements.

Generalizing, the Arctic and sub-Arctic hydroelectric plants make use of river systems which, even under winter conditions, provide some flow which can be stored and utilized in lakes or man-made reservoirs. Smaller lakes can also be tapped by means of tunnels and penstocks to a power plant at a lower elevation. The generating capabilities of these plants must be designed to make best use of the peculiar hydrology of the Far North. During long periods of cold weather, reservoirs and lakes can be drawn down below their insulated blanket of ice to such levels as the designer feels the history of input flow records will permit. During warmer periods of time when runoff occurs, the lakes or reservoirs can be replenished. The generating characteristics will have seasonal peaks. There are many other design and operating factors which must be considered. Some of these are summarized in a statement by Honorable Arthur Laing, Minister of Indian Affairs and Northern Development, Ottawa:[1] "Cold weather conditions do not constitute an operating problem other than creating a certain degree of discomfort for personnel obliged to work outdoors which in turn aggravates the staffing problem. From the technical point of view, it is mandatory that appropriate measures be taken at the design stage to guard against sub-zero conditions, chief of which are provisions of heating, and where practicable adequate insulation, for pipe lines and tanks, use of submerged weirs, heated gates and gate guides, and adequate cross-section of canals to ensure low velocities and the formation of a "board ice" cover and at the same time, avoidance of frazil or anchor ice formation." The Alaska hydroelectric power plants at Eklutna (U.S. Bureau of Reclamation) near Anchorage and the Cooper Lake project on Kenai Lake of the Chugach Electric Association Inc. have operated without undue difficulty even during extended periods of cold weather in the low minus-thirties. Provisions for heating gates, surge tanks and burying penstock portions below the surface of the ground are among design concepts which add very little cost. Tailrace discharges were also designed to anticipate possible problems: none has yet arisen.

ALASKA

Alaska's water potential has been reconnoitered for many years especially by the U.S. Army Corps of Engineers District Alaska. Some projects have been examined by the U.S. Bureau of Reclamation, and others by electric supply cooperatives and private organizations. By and large, with a few exceptions, the roster of potential projects can be termed of a reconnaissance nature. This is true as well with most hydro in other parts of the North Pacific country. The greatest handicap in this work has been the paucity and reliability of water records of any significant length of time. In addition, only a few sites have been investigated for foundation and reservoir feasibility. Some of them may be ruled out by questions of permeability. Less than a handful of potential projects have been carried through preliminary design consideration, and analysis of potential capital and operating costs. Some of the exception will be very briefly reviewed although it is necessary to indicate that for most the design approach so far has been conservative rather than imaginative: the lessons we might learn from the Soviet in their Arctic and sub-arctic water control projects have not been applied except in a miserly manner.

Table 2 "Tentative Listing of Hydroelectric Power Sites in Alaska" is just that: tentative and subject to change. It covers projects with installed capacity ranging downward from the 5 million kilowatts Rampart project on the Yukon to small lake-diversion projects in southeast Alaska with 12,000 to 15,000 kilowatts. These projects encompass a wide range of estimated bus-bar power costs for firm energy: from 2 mills at Rampart to over 16 mills at Tuksuk in northwestern Alaska. Project firm energy production estimates range from over 34 billion kilowatt hours per year at Rampart to 31 million at the Deer project in the Panhandle. Estimated construction costs vary from $200 per installed kilowatt at Rampart to $1,800 at Tuksuk.

In terms of power supply for the processing of concentrates, or for the electroprocessing of imported materials as alumina from Australia, there are probably not more than three possible hydroelectric projects in Alaska which would qualify for sufficiently low costs of generated power. These are the Rampart project on the Yukon River, about 100 air-miles northwest of Fairbanks with an estimated 2 mills per kilowatt-hour at bus-bar for firm energy; the Wood Canyon project on the Copper River with an estimated 3 mills per kilowatt-hour also at bus-bar for firm energy, and the Yukon-Taiya project near Skagway, Alaska with an estimated 2.9 mills per kilowatt-hour for firm energy at bus. A somewhat different scheme, the Yukon-Taku, diverting the upper Yukon system into the head of Taku Inlet near Tulsequah in northern British Columbia, is discussed further on with regard to that Province.

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[1] Personal communications of January 16, 1967.

These three major hydro projects certainly have one thing in common: they have been and are controversial. The Yukon-Taiya project and its alternative, the Yukon-Taku, have been in question ever since inception of studies. However, either project is good and the international complications can be resolved. In this regard, relations between the U.S. and Canada as witness the Upper Columbia River Treaty show clearly that mutuality of interest bridge many problems.

The Wood Canyon project faces a more formidable basic problem: fish. If built, the dam would straddle one of the greatest salmon producing streams in the world. Although it is conceivable that fish passage and propagation could be accomplished, the question would be one of acceptability by fisheries people and of additional cost. In this instance, the world famine problem lays stress on the preservation of a major food resource and thus the consideration of the Wood Canyon project should be abandoned or deferred.

"Rampart" has become an internationally dirty word. It has been subjected to a most intensive campaign of vilification based on ill-defined and unsupported claims that the project would completely annihilate a major migratory-bird breeding ground, an important salmon run, and countless animals such as moose and the like. The campaign against Rampart has been mounted by officials from governmental and other organizations concerned with fish and wildlife and the preservation of areas for the contemplation of natural beauties. The hue-and-cry has caused the present Secretary of the Interior literally to sit on staff reports on this project for years. The tactics are obvious: to delay is to destroy. Also recent so-called studies apparently "load" project estimates with all kinds of extraneous costs. By such devious tactics, the project can be shown to be totally uneconomic.

The unalterable fact, notwithstanding government officials, and academicians in the hire of wildlife and conservation fanatics, is that the Rampart project with its 5 million kilowatts of installed capacity could be the most powerful influence on the development of Alaska outside of its oil and gas industry. Eventually made part of an international power grid system, its capabilities could be increased for peaking and benefits increased enormously. As we view the total needs for electric power in the North American continent, Rampart's contribution will be needed. It represents a renewable resource of tremendous importance.

TABLE 2.—TENTATIVE LISTING OF HYDROELECTRIC POWER SITES IN ALASKA, 1966

Project	Stream or lake	Continuous power		Installation at 50 percent load factor		
		Capacity, megawatts	Firm energy, 10⁶ kilowatt-hours per year	Installed capacity, megawatts	Construction cost per installed kilowatt	Bus bar rate for firm energy, mills per kilowatt-hour
NORTHWEST						
1. Agashashok (Igichuk)	Noatak River	93	820	186	$800	7.8
2. Misheguk (Upper Canyon).	do	87	760	174	1,000	9.7
3. Nimiuktuk	do	70	613	140	1,200	11.3
4. Kobuk River	Kobuk River	60	526	120	1,500	14.0
5. Tuksuk (Imuruk Basin).	Tuksuk Channel	33	289	66	1,800	16.5
INTERIOR						
6. Holy Cross	Yukon River	1,400	12,300	2,800	800	8.0
7. Dulbi	Koyukuk River	122	1,070	244	1,400	13.2
8. Hughes	do	55	482	110	1,000	10.0
9. Kanuti	do	184	1,612	368	1,200	10.8
10. Melozitna	Melozitna River	32	282	64	1,100	10.1
11. Ruby	Yukon River	730	6,400	1,460	400	3.5
12. Junction Island	Tanana River	266	2,330	532	1,500	13.4
13. Bruskasna	Nenana River			(40)		
14. Carlo	do	96	840	(30)	1,000	9.5
15. Healy (Slagle)	do			(130)		
16. Big Delta	Tanana River	113	987	226	1,600	14.9
17. Gerstle	do	50	438	100	1,600	15.1
18. Johnson	do	105	920	210	1,600	14.3
19. Cathedral Bluffs	do	79	693	158	1,500	13.6
20. Rampart	Yukon River	3,904	34,200	[1] 5,040	200	2.0
21. Porcupine (Campbell River).	Procupine River	265	2,320	530	500	4.5
22. Woodchopper	Yukon River	1,620	14,200	[1] 2,160	500	4.3
23. Fortymile	Fortymile River	83	723	166	800	8.0
24. Yukon-Taiya	Yukon River	2,400	21,000	[1] 3,200	300	2.9

TABLE 2.—TENTATIVE LISTING OF HYDROELECTRIC POWER SITES IN ALASKA, 1966—Continued

Project	Stream or lake	Continuous power		Installation at 50 percent load factor		
		Capacity, megawatts	Firm energy, 10^6 kilowatt-hours per year	Installed capacity, megawatts	Construction cost per installed kilowatt	Bus bar rate for firm energy, mills per kilowatt-hour
SOUTHWEST						
25. Crooked Creek	Huskokwim River	1,070	9,400	2,140	500	4.8
26. Nuyakuk	Nuyakuk River	63	555	127	1,500	14.1
27. Lake Iliamna	Kvichak River	156	1,370	313	1,100	9.9
28. Tazimina	Tazimina River	26	224	51	1,500	13.5
29. Ingersol (Lackbuna Lake).	Kijik River	72	630	144	1,300	12.7
30. Kukaklek	Alagnak River	27	232	53	1,000	9.7
31. Naknek	Naknek River	54	473	108	1,200	11.8
SOUTH CENTRAL						
32. Crescent Lake	Lake Fork of Crescent	20	179	41	900	8.9
33. Chakachamna	Chakachatna River	183	1,600	366	600	5.8
34. Coffee	Beluga River	18	160	37	1,100	10.3
35. Upper Beluga (Beluga River).	do	24	210	48	1,000	10.0
36. Yentna	Yentna River			(145)		
37. Talachulitna (Shell)	Skwentna River	159	1,390	(75)	1,000	9.0
38. Skwentna (Hayes)	do			(98)		
39. Lower Chulitna	Chulitna River	45	394	90	800	7.3
40. Tokichitna	do	92	806	184	800	7.8
41. Keetna (Talkeetna)	Talkeetna River	37	324	74	1,100	10.2
42. Whiskers	Susitna River	42	368	84	1,100	10.3
43. Lane	do	120	1,052	240	800	8.0
44. Gold	do	130	1,139	260	1,300	11.7
45. Devil Canyon	do			(738)		
46. Watana	do	801	7,000	(478)	500	4.9
47. Vee	do			(386)		
48. Denali	do			(—)		
49. Snow	Snow River	32	278	63	1,000	9.8
50. Bradley Lake	Bradley Creek	47	410	94	600	6.0
51. Lowe (Keystone Canyon).	Lowe River	29	254	58	1,000	10.6
52. Million Dollar	Copper River	220	1,927	440	1,400	13.1
53. Cleve (Peninsula)	do	410	3,600	820	1,300	11.8
54. Wood Canyon	do	2,500	21,900	[2] 3,600	300	3.0
SOUTHEAST						
55. Chilkat	Chilkat River	21	180	41	950	9.5
56. Lake Dorothy	Dorothy Creek	17	150	34	600	6.9
57. Speel Division Snettisham.	Speel River	31	275	63	800	7.2
58. Tease Creek	Tease Creek	8	70	16	1,400	13.3
59. Sweetheart Falls Creek	Sweetheart Falls Creek.	14	125	29	800	8.7
60. Houghton	Unnamed	15	136	31	1,000	10.0
61. Scenery Creek	Scenery Creek	8	67	15	800	10.0
62. Thomas Bay (Cascade Creek).	Cascade Creek	19	166	38	600	7.3
63. Stikine River	Stikine River	1,130	9,900	2,260	900	8.0
64. Goat	Goat Creek	10	87	20	1,200	12.1
65. Tyee Creek	Tyee Creek	14	120	27	600	7.4
66. Spur	Unnamed	12	105	24	900	9.8
67. Leduc	Leduc River	7	62	14	1,100	13.3
68. Rudyerd	Unnamed	9	83	19	800	9.7
69. Punchbowl Creek	Punchbowl Creek	7	64	15	800	10.5
70. Red	Red River	12	104	24	1,000	11.0
71. Lake Grace	Grace Creek	11	94	21	700	8.7
72. Swan Lake (Lower Swan Lake).	Falls Creek	8	69	15	900	10.9
73. Maksoutof River	Maksoutof River	14	124	28	900	9.6
74. Deer	Unnamed	3½	31	7	900	13.7
75. Takatz Creek	Takatz Creek	11	97	21	900	9.3
76. Green Lake	Vodopad River	6	51	12	1,000	12.8
77. Kupreanoff	Lake and stream system near Petersburg.	27				4.8

[1] Based on 75 percent load factor.
[2] Based on 69.4 percent load factor.

Source: U.S. Corps of Engineers, U.S. Bureau of Reclamation, Alaska State Department of Natural Resources, Ivan Bloch & Associates.

Rampart, together with an initial transmission network to tidewater in the Cook Inlet area, could provide large blocks of low-cost power suitable for major electroprocess industry development. The world-famous consulting firm of Development and Resources Corporation, headed by Mr. David Lilienthal of TVA and AEC background, concluded that the output of the project could be absorbed in its entirety in Alaska on the basis of power costs as indicated. Although the studies of Lilienthal's group were completed in 1962, there is very little of substance which would require a revision of marketability for electroprocess industries.

In summary, Alaska's hydroelectric resources are large but with some major exceptions, high in estimated power costs.

YUKON AND NORTHWEST TERRITORIES [2]

Excluding the drainage of the Mackenzie River, the dominant stream regimen of this vast area is the Yukon River and its upper tributaries. These include the Stewart and Pelly Rivers. Hydroelectric development to date has been sparse.

In the Yukon, there were five hydro plants in 1966 but one was scheduled to be shut-down in 1967 due to cessation of gold dredging operations. These plants included Whitehorse Hydro (11,250 kilowatts); Mayo Hydro (5,100 kilowatts used principally for nearby lead-zinc mines); Porter Creek and McIntyre Creek hydros (1,000 and 650 kilowatts respectively) and Dawson North Forks (10,050 kilowatts used for gold dredging and to be shut-down). There were many individual small diesel-electric generating plants, usually under 250 kilowatts for individual community requirements.

In the Northwest Territories, the four hydroelectric plants were in the drainage of the Great Slave Lake region. This included two on the Snare River (each with 7,000 kilowatts of capacity) and used principally for Yellowknife Gold mines and townsite; Taltson River hydro (18,000 kilowatts) used mainly for the Pine Point Mines and the towns of Fort Smith and Pine Point; and Bluefish Hydro (3,500 kilowatts). There were also four thermal power plants having capacities in excess of 1,000 kilowatts.

The Yukon drainage has received more study than any other in the area. Some schemes of development entail diversions either into the United States in Alaska, or in Northern British Columbia. Table 3 "Tentative Listing of Hydroelectric Projects in Yukon" contains official data for two major schemes of integrated development. The so-called "major system" development makes use of the flows of the upper Yukon system without any diversions into either Alaska or British Columbia. It is estimated that over 6,000 megawatts of installed capacity or 5,300 megawatts of firm power at 75% load factor might be developed in this manner. An estimated capital cost for the development of this kind of system, centering about Whitehorse, has been stated at $2.5 billion. Although each power plant would represent a different investment per unit of capacity, the arithmetic average for the system as described would be slightly over $400 per kilowatt of installed capacity.[3]

Most interest to date has been shown in the possibilities of diverting a portion of the flow of the upper Yukon into Alaska near Skagway at the head of Lynn Canal, or into British Columbia near Tulsequah at the head of Taku Arm. The first project, known as the Yukon-Taiya, has been investigated by the Aluminum Company of America and also the U.S. Bureau of Reclamation. The second or alternative project, the Yukon-Taku, was surveyed by the Frobisher interests. Either project would divert from 21,000 to 24,000 cubic feet per second from the upper Yukon and various tributary streams. It has been calculated that this diversion would reduce the flow of the Yukon at the Canadian-Alaska Border by some 30%. By the same token, some sites (a total of 7 out of the 17 listed in the "major system") would no longer be effective.

The "modified system" would have an installed capacity totalling almost 3,500 megawatts of which 2,800 megawatts could be considered as firm power at a 75% load factor. The approximate value of capacity which would be developed at the Yukon-Taiya diversion project into Alaska has been stated as ranging from 900 to 2,400 megawatts; that at the Yukon-Taku diversion into British Columbia would be about 3,600 megawatts. These capacity data are quite tentative.

Cost estimates on the two major diversion projects are quite dated. Early esti-

[2] Data on existing development from personal communication, dated Jan. 16, 1967 from Hon. Arthur Laing, Minister of Indian Affairs and Northern Development.

[3] Data on the Yukon were obtained mostly from "Potential Hydropower Resources of the Yukon," by H. T. Ramsden, District Engineer, British Columbia and Yukon District Water Resources Branch, Department of Northern Affairs and National Resources, Vancouver, B.C.

mates for the Yukon-Taiya were in the area of 2.1 mills per kilowatt hour.[4] For the Yukon-Taku project, costs were estimated in the range 3.0–3.5 mills per kilowatt-hour.[5] More recent reviews on the Yukon-Taiya listed possible power costs at 2.9 mills per kilowatt-hour on a 50% load factor basis.[6] There is little question that the alternative projects can be considered among the top few for lowest cost power in the North Pacific Country. The international problems probably can be overcome as the benefits which would accrue both to Canada and Alaska become clearer. There are other problems regarding the effect of diversion on the main stem of the Yukon, and the physical aspects of deep-draft access to the head of Taku Arm for major industry establishment which may prove to be more knotty.

TABLE 3.—*Tentative listing of hydroelectric projects in Yukon*[1]

A. MAJOR SYSTEM[2]

River system and project	*Installed capacity in megawatts*
1. Miles Canyon, main stem Yukon	(3)
2. Whitehorse Rapids, main stem Yukon	54
3. Hootalinqua, main stem Yukon	259
4. Big Salmon, main stem Yukon	301
5. Five Finger Rapids, main stem Yukon	455
6. Wolverine, main stem Yukon	476
7. Britannia, main stem Yukon	459
8. Ogilvie, main stem Yukon	896
9. Dawson, main stem Yukon	571
10. Boundary, main stem Yukon	1,006
11. Swift River, Teslin River	157
12. Detour, Pelly River	(3)
13. Granite Canyon, Pelly River	254
14. Bradens Canyon, Pelly River	180
15. Fraser Falls, Stewart River	347
16. Independence, Stewart River	431
17. Porcupine, Stewart River	223
Total	[4] 6,069

[1] Ramsden, H. T., "Potential Hydro Resources of the Yukon", Department of Northern Affairs and National Resources, Vancouver, B.C. (Before Northern Resources Conference, Whitehorse, Y.T., Mar. 22, 1963; U.S. Department of the Interior, Bureau of Reclamation, "Interim Report on the Yukon-Talya Project", 1951 (and later personal communications).
[2] Without any diversions out of Yukon Territory.
[3] Storage.
[4] 5,300 MW of firm power, 75% L.F.

B. MODIFIED SYSTEM[5]

	Installed capacity in megawatts
1. Britannia, main stem Yukon	240
2. Ogilvie, main stem Yukon	560
3. Dawson, main stem Yukon	437
4. Boundary, main stem Yukon	783
5. Detour, Pelly River	(3)
6. Granite Canyon, Pelly River	254
7. Bradens Canyon, Pelly River	180
8. Fraser Falls, Stewart River	347
9. Independence, Stewart River	431
10. Porcupine, Stewart River	223
Total	[6] 3,455
Yukon-Taku, Taku project—diversion into tidal B.C	[7] 3,600
Yukon-Taiya project—diversion into tidal United States	[8] 900–2,500

[5] Showing effect of Yukon-Taku diversion—should be considered with it.
[6] 2,800 MW of firm power, 75% L.F.
[7] Continuous power.
[8] Installed.

[4] U.S. Department of the Interior, Bureau of Reclamation "Interim Report on the Yukon-Taiya Project", 1951.
[5] Battelle Memorial Institute, "An Integrater Transport System to Encourage Economic Development of Northwest North America" for the Alaska International Rail and Highway Commission, 1961.
[6] U.S. Department of the Interior, Field Report "The Rampart Project, Alaska", Juneau, Alaska, January 1965.

NORTHERN BRITISH COLUMBIA

The Province of British Columbia indubitably has some of the most exciting hydroelectric potentials of North America. It has many river systems with substantial flows and with some very large storage sites and possibilities for flow integration. As investigations continue, the estimates of potential have grown larger and larger. For example, the classic "Water Powers of British Columbia" issued in the early 1920s[7] stated "The total available water-power of the Province has been variously estimated at from 2,000,000 to 2,500,000 horse-power though these estimates include certain sites on the Lower Fraser, Thompson and Skeena Rivers where the presence of main lines of railroads has rendered development improbable." In 1942, the Water Rights Branch of the Provincial Government estimated possibilities for development on the order of six to eight million horsepower.[8] One year later, the Dominion Water and Power Bureau hiked the estimates to a range between seven and almost eleven million horse-power.[9] (The ranges indicated were for ordinary minimum, and ordinary six months flows). Today, investigations in greater detail and the application of the concept of stream regulation by storage and diversion have resulted in estimates in excess of 30 million horse-power[10], and there are some who believe these grossly understate the potential.

There are several major potential developments: those of the Peace River and its tributaries, those of the Fraser and its tributaries, and various coastal river regimen such as the Skeena, Stikine, Iskut and others. For the purposes of this discussion, however, potentials which exist below a line of demarkation roughly extending from Prince Rupert along the Skeena to Prince George and eastward the Lesser Slave Lake are not considered. What is left are the stream regimen of the Liard, the diversion of the Upper Yukon into British Columbia at Tulsequah (Yukon-Taku project), the Stikine and Iskut, the Skeena and the Nass, and the Peace. Table 4 "Summary of Undeveloped and Developed Power Sites in British Columbia" lists these for the entire Province and indicates a total of almost 26 million kilowatts for undeveloped and developed sites. An extensive index of undeveloped power sites is on file at the Office of the Deputy Minister of Water Resources, Department of Lands, Forests and Water Resources, Vancouver, B.C. This index "is a tabulation of *known* undeveloped hydro power sites, and does not represent the total potential of the Province since no data exist for many tentative sites. In addition, the site investigation and flow records available for the majority of the sites listed are fragmentary and therefore the potential assigned to a particular site may change markedly when better basic data are available."

The listed undeveloped sites, including the Peace, total close to 12 million kilowatts of which the upper and lower Peace account for over 2½ million kilowatts of potential capacity.[11] Construction of the Portage Mountain dam and project on the upper Peace is well under way under the auspices of the B.C. Hydro and Power Commission. The dam was approximately 80% complete at the end of 1966, and it is expected the first turbines will be installed in late 1967 so that power delivery can commence in late 1968. This great project together with one downstream plant will have an installed capacity of 3 million kilowatts with possibly another 1 million at additional downstream plants.

The harnessing of the Liard River system is in early planning stages by the Province of British Columbia. B.C. Hydro and Power Commission estimates these projects would have a potential of 3 to 4 million kilowatts. The Stikine and Iskut Rivers are also being investigated. On the basis of preliminary studies and surveys, generation sites may not be economically attractive according to present standards. However, the river systems might eventually provide large blocks of power for the mining, pulp and paper industry almost certain to develop in the Prince Rupert environs.[12]

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[7] British Columbia Department of Lands, Victoria, B.C.

[8] Davis, Ernest (Water Rights Branch, British Columbia) "Water Power in British Columbia, "The Canadian Institute of Mining and Metallurgy Bulletin, Annual Western Meeting, Vancouver, B.C., 1942.

[9] Dominion Water and Power Bureau, Department of Mines and Resources, "Water Power Development—Canada : 1942." The Canadian Mining and Metallurgical Bulletin 1943.

[10] Paget, A. F., Deputy Minister of Water Resources, British Columbia Department of Lands, Forests and Water Resources, Victoria, B.C., "Annual Review—Water Powers of B.C.," July 1966.

[11] B. C. Hydro and Power Authority estimates the Peace potential at close to 4 million kilowatts of installed capacity, "The Power of British Columbia," February 1967.

[12] Personal communication of Feb. 14, 1967, from Hon. H. S. Keenleyside, Chairman of B.C. Hydro and Power Commission.

The tremendous growth in power demands principally, but not exclusively, in southern British Columbia in the lower Fraser Valley will "sop" up generation as soon as it comes on the line. At present, it appears that as the upper Peace project and Columbia River Treaty plants come into generation phases, their output will be absorbed. This means that the Liard and possibly other river systems will require development at an early date to meet power requirements in British Columbia, let alone to provide any surplus for sale to the United States.

It is important to stress the fact that the Peace and Columbia River Treaty projects are part of a planned regional transmission system.

TABLE 4.—SUMMARY OF UNDEVELOPED AND DEVELOPED POWER SITES IN BRITISH COLUMBIA [1]

Area	Description	Undeveloped power megawatts	Developed power, average megawatts
Northern British Columbia coast	Including Yukon-Taku diversion	3,930.0	
Upper Liard	Including parts of Nahanni	2,400.0	
Lower northern coast	Including Stikine and Iskut Rivers	890.0	
Skeena and Nass Basin	Including Skeena and Nass Rivers	1,880.0	9.4
Peace River:			
Upper	Stream system above Hudson Hope	1,980.0	(2)
Lower	Stream system below Hudson Hope	570.0	
Subtotal for northern British Columbia		11,650.0	9.4
Central coast	Rivers inlet north to Skeena Basin, Queen Charlotte Island.	280.0	14.5
Nechako and Upper Fraser	Fraser above Macalister, British Columbia	1,550.0	707.0
Lower coastal	Vancouver north to rivers inlet	1,070.0	309.0
Vancouver Island	Vancouver Island rivers	220.0	290.0
Lower Fraser	Below Macalister, British Columbia	5,130.0	720.0
Thompson	Thompson River and tributaries	1,440.0	5.2
Columbia River	Columbia River in Canada	2,590.0	[3] 602.0
Subtotal for southern British Columbia		12,280.0	2,647.7
Total for all of British Columbia		23,930.0	2,657.1

[1] Paget, A. F., Deputy Minister of Water Resources, Department of Lands, Forests, and Water Resources, Province of British Columbia, Victoria, British Columbia, "Annual Review—Water Powers," July 1966.
[2] Under construction.
[3] Others under construction.

In time, coordination of the system will be effected with the U.S. Columbia River System, and the high-voltage, high-capacity Pacific Northwest-Pacific Southwest grid. Policies and rate schedules for the upper British Columbia system have not as yet been finalized. It is probable, however, that the average cost of power will center in the 3–4 mills per kilowatt-hour area, and possibly less at or close to bus-bar generation points.

Thermal Energy (Conventional)

Fossil fuel resources of the North Pacific Country are very large but still largely unexplored and unused. The areas of principal development to date are in the Cook Inlet-Kenai Peninsula area of Alaska for petroleum and natural gas, the Matanuska and Healy River fields for coal, and the region extending around the Peace River including Fort St. John, Hudson Hope and Fort Nelson for natural gas and petroleum.

The potential for these resources is difficult to define even in the grossest of terms. That the resources are large and almost ubiquitous in the North Pacific region seems an incontrovertible fact. For instance, Alaska contains probably well over 100 billion tons of coal, ranging from anthracites and semi-anthracites to lignitic to bituminous to subbituminous coals. The areas of occurrence include the northern Alaska Peninsula area on the Arctic Ocean, centering about Point Barrow; the Upper Yukon; the Nenana and Broad Pass fields in the Alaska Range where it is cut by the Alaska Railroad; the Matanuska Valley and portions of the Kenai Peninsula on Cook Inlet; and the Bering River field. There is also a large field of subbituminous, strippable coal in the Beluga area of north Cook Inlet, and also across Cook Inlet on the Kenai Peninsula. The Beluga field seems much more promising than that on the Kenai Peninsula.

With regard to petroleum and natural gas, there is no question that a major field has been discovered in the Cook Inlet area since its exploitation began during the past decade. A total of over sixty wells have been in operation with a total cumulative production as of March 1966 of over 52 million barrels. Reserves are now estimated at more than 1 billion barrels. The same general area has become also a tremendous producer of natural gas. Cumulative production as of March 1966 was estimated at over fifty billion cubic feet. Reserves have been estimated at 4 trillion cubic feet.[13] In the Artic Slope area, stretching on the Arctic Ocean and Chukchi Sea between parallels 140 to 165 degrees, there is another oil and gas province which appears promising. In the Umiat area alone, reserves estimated from exploratory drilling and some small production have been stated on the order of 50 to 60 million barrels. No data are available on what the gas reserves may be: it is likely they will be enormous.

The availability of natural gas in very great quantities surplus to the immediate and foreseeable future needs of the Cook Inlet area is basic to the announced plans for industrial utilization in the same area. The Collier Carbon Chemical Co., subsidiary of Union Oil, is building a 1,500 tons per day ammonia plant. It is also building a prilled urea plant with a capacity of 1,000 tons per day. The plant will be jointly owned with Japan Gas Chemical Co. In addition, the U.S. Federal Power Commission in late April 1967 cleared the way for the building of a large cryogenic natural-gas liquefaction plant by Phillips Petroleum and Marathon Oil companies. The output will be shipped by specially-designed LNG tankers to Japan for sale to the Tokyo Electric Power Co., Inc. and the Tokyo Natural Gas Co. Ltd. The gas will be sold at a rate of 52 cents per million Btus delivered.[14] All three plants will be situated on the Kenai Peninsula, on the south shore of Cook Inlet. There have been notices to the effect that Skelly Oil and a Japanese group are also considering building a very large methanol plant. An alternative location might be Canada.

The magnitude of the interest in Alaska may be also gauged by the fact that virtually all major oil companies are involved in activities ranging from actual production to major-scale exploration.[15] This includes Standard of Indiana, Phillips, Sinclair, Skelly, Atlantic Richfield, Shell, Union, Mobil, Texaco and Standard of California. The Alaska areas of intense interest include the Cook Inlet region, the Arctic North Slope, Bristol Bay on the west, and the Gulf of Alaska to the south.

Table 5 "Fossil Fuel Reserves and Estimated Fuel Values at Sources in Alaska" is a recent attempt to provide a sense of perspective. It is the writer's opinion that estimates of fuel cost are conservative and could be lower depending on scale of production.

In the Yukon, Northwest Territory and northern British Columbia are a number of coal fields which run the entire gamut in rank. Large quantities of lignites are in reserves along the Arctic Coast, the Peel River and Old Crow districts. Similar reserves are noted in the Dawson, Kluane and Watson Lake areas. Bituminous-ranking coals are found in the Atlin, Dease and Ground Hog areas, the Telkwa field north of Hazelton and around Prince George. The Peace River area, extending also into Alberta contains very great quantities of both bituminous and lignitic coals. There are possibly around 300 million tons of bituminous coal and 1,500 million tons of lignitic coal in the Yukon. Northwest Territory known-reserves are small, about the order of 16 or so million tons. Northern British Columbia reserves, mainly bituminous coal, are on the scale of 2,100 million tons.

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[13] Senator E. L. Bartlett, of Alaska, Congressional Record, Senate, Apr. 28, 1967, pp. S 6027–6030.

[14] U.S. Federal Power Commission "FPC Authorizes Two U.S. Firms To Export Liquified Natural Gas from Alaska to Japan; release No. 14896, Apr. 19, 1967.

[15] A review of the Alaska natural gas industry has just been released by the University of Alaska's Institute of Social, Economic and Government Research; Review of Business and Economic Conditions: "The Natural Gas Industry in Alaska," February 1967.

TABLE 5.—FOSSIL FUEL RESERVES AND ESTIMATED FUEL VALUES AT SOURCE IN ALASKA

General area	Type of fuel	Probable reserves	Estimated fuel cost at source (cents per million b.t.u.)	Remarks
Coal:				
Arctic slope	Bituminous and subbituminous coal	Huge, 80,000,000,000 tons	Unknown	Suitable for strip mining, undeveloped.
Kobuk	Bituminous coal	Unknown	Unknown	Undeveloped.
Bettles	do	do	Unknown	Do.
Kugruk	Lignitic coal	do	Unknown	Slight development.
Fairbanks and northern railbelt (Nenana field)	Lignitic and subbituminous coal	5,000,000,000 plus tons	30–50	Mined for many years. Several million tons strippable reserves of subbituminous and lignitic coal. Large tonnage prospects are good. Location of mine-mouth steam-electric plant of Golden Valley Electric Association, Inc.
Big Delta (Jarvis field)	Subbituminous coal	50,000,000 to 70,000,000 tons	40–55	Fairly thin but strippable beds.
Central railbelt (Broad Pass field)	Subbituminous and lignitic coal	60,000,000 plus tons	35–50	Some development, strippable beds.
Matanuska and Anchorage (Matanuska field)	Bituminous coal	130,000,000 to 200,000,000 plus tons.	35–50	Developed in part; used for Anchorage steam-electric power and steam plants. Limited reserves for strip mining.
North Cook Inlet (Beluga field)	Subbituminous coal	250,000,000 plus tons	20–30	Thick lenses suitable for strip mining.
Homer (Kenai field)	do	400,000,000 tons	Unknown	Minor development near Homer. Probably high-cost mining in thin, intercalated seams.
Gulf of Alaska (Bering River field)	Anthracite and bituminous coal	3,000,000,000 plus tons	Unknown	Mining probably difficult.
Petroleum and natural gas:				
Arctic slope (Umiat-Gubik field)	Gas and oil	Unknown but large	Unknown	Not delineated. Gubik stated at 22,000,000,000 cubic feet of gas for tested sands and 295,000,000,000 for untested sands. Naval Petroleum Reserve No. 4 area might contain close to 1,000,000,000 barrels oil in place.
Lower Yukon-Kuskokwim	Oil and possibly gas	Unknown	Unknown	Considered an oil province.
Alaska Peninsula-Cook Inlet area	Oil and gas	At least 10,000,000,000,000 cubic feet of gas and many millions of barrels of oil.	15–18	Major oil and gas producing area. 2 gas turbine power generating plants, and 1 planned by Chugach Electric Association, Inc.

Source: Alaska Department of Natural Resources, U.S. Bureau of Mines, U.S. Geological Survey, Battelle Memorial Institute, Ivan Bloch & Associates.

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The North Pacific Country in Canada has huge potential reserves of petroleum oil and natural gas, and natural gas liquids. Development has occurred in recent years at a phenomenal rate but mostly in the so-called Peace river area of Northern British Columbia which now supplies important markets by major pipelines extending southward to the populous lower Fraser River Valley and to the United States; and eastward in Canada. The oil and gas provinces contain a vast area ranging in a southeasterly direction generally from the Arctic Basin of the Mackenzie, along the Mackenzie, and then co-extending with the Rocky Mountains area on both sides of its drainages. The principal area of commercial activity on a major producing scale is in the northeastern portion of British Columbia. This is in an area roughly bounded to the north by the British Columbia-Yukon line, on the west by the Rocky Mountains, and to the east by the British Columbia-Alberta boundary.

Development of petroleum and natural gas in the Yukon has been minor to date. Reserves have been variously estimated at around 3 million barrels of oil; the potential of natural gas is unknown. Northwest Territory has sizeable reserves of oil and gas. In 1964, petroleum crude reserves were estimated close to 50 million barrels with natural gas stated on the order of 55 or more billion cubic feet. These data probably underestimated potential quite severely. British Columbia, on the other hand, has demonstrated the magnitude of its resources of oil and gas. In 1964, the reserves of crude were stated in excess of 200 million barrels, with natural gas close to 7 trillion cubic feet. The potential is likely to be much greater. Some believe gas potentials will be near 100 trillion cubic feet, with petroleum around 500 million barriels.[16]

Numerous pipeline companies have established a network of transmission lines to tap the wells of the Northern British Columbia area. Natural gas is piped down from the Fort Nelson area to the Peace River area where the output from a number of producing areas is picked up near Fort St. John for transport south to the Vancouver area and to the U.S. An interconnection to the east occurs west of Kamloops. Similarly, pipe lines transport oil from the Peace River area around Fort St. John, south to the Vancouver area, and also to the Pacific Northwest's refineries in the Ferndale and Annacortes areas of Washington. An interconnection to Edmonton fields and eastward is made just north of Kamloops. In 1964, there were about 1,260 miles of oil transmission lines and almost 1,800 miles of natural gas transmission lines. These data exclude field gathering or delivery lines.

There are many emerging possibilities for the industrial use of the petroleum and natural gas resources of the area. Discussions are current regarding the export of liquified natural gas at a "super-port" proposed of establishment at Roberts Bank at deep-water south of Vancouver. The possibilities of producing ammonia, fertilizer, methanol are almost certain to develop.

With regard to the cost of North Pacific Country fossil fuels, it is impossible to generalize as each individual location and situation will result in widely varying levels per million Btu's. One thing is certain, actual past experience may not be the best guide for deriving even rough estimates. For instance, coal mining in Alaska has never achieved a stability or volume warranting the kinds of operations which result in low costs. In many ways, it has been a "pick, shovel and bushel basket" proposition: The vagaries of military fuel contracts, on a year-by-year basis, rendered financing for modern equipment and mining well-nigh impossible. As to oil and natural gas, the picture is somewhat clearer. Yet, each field's appraisal will be a specialized one combining the impact of the size of market, the effect of development and lifting costs, and transportation. Obviously, quite often it is the concept of what the market will bear which will determine price level. Various estimates range from 6 to 16 cents per MCF at well-head for natural gas.

As in any other industrial operation, the eventual cost of power as delivered to a consumer depends on the capital costs of the power system and its operating costs. In the case of hydroelectric projects, the proportion of capital costs to total power cost is much greater than its operating costs. But, in the case of conventional thermal plants using coal, oil or gas as a fuel, the reverse is true.

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[16] Reserve data from various sources: Canadian Minerals Yearbook for 1964; 15 B.C. Natural Resources Conference, 1964; Department of Mines and Technical Surveys, Ottawa, "A Survey of the Petroleum Industry of Canada" (annual); Ministry of Northern Affairs and Natural Resources, Ottawa, "Economics of Oil and Gas Development in Northern Canada," 1962; B.C. Hydro and Power Authority, "The Power of British Columbia," February 1967.

Capital costs are a smaller proportion of total than fuel and operating costs. Obviously, the capital costs (or fixed charges) depend on the size and kind of installation, its life or period for depreciation replacements, the cost of money and insurance and taxes on the overall investment. Operating costs include maintenance, labor, supervision, lubrication and fuel costs in the case of thermal plants.

The size of the power plant (and the rest of the system) has considerable influence on both capital and operating costs. The costs per unit of production reflect markedly the economies of size. The larger the generating plant, the less its capital cost per unit of generation and the more efficient it can be. This is certainly applicable to thermal power plants, and usually also for hydro assuming dam, reservoir sites and the hydrology are comparatively sound. On the other hand, as units get larger, some of the mechanisms become more complex, and any shut-down time is much more costly than for smaller units. Larger units are less flexible usually in their operating characteristics and function best as part of a total power system than as individual, isolated units. This places a premium on intergrated power systems containing many generating units and transmission systems interconnecting many diverse markets.

With regard to hydro generating plants, there are a number of ways in which to appraise eventual costs per kilowatt and kilowatt-hours which are principally composed of fixed charges. The physical structure of the dam and reservoir complex, assuming proper design and construction, should last for many years. The actual life might be many hundreds of years depending largely by the accumulation of silt rather than "wear and tear". Electrical equipment, especially rotating and switching gear, should have a useful life up to 50 years assuming appropriate maintenance and occasional replacement of critical parts. However, the determinant for the permissible period of time for retirement or amortization of investment is related to the effect of the interest component on the capital investment. Thus, the "life" of hydro plants is usually set between 50 and 100 years, with 75 years as a mid-point. In addition, in the United States, Federal multiple-purpose water-control projects which contain power generating features are given the benefit of cost-allocations. That is, certain functions such as flood control, navigation, recreation, fish enhancement, and non-agricultural water supply are cosidered as non-reimbursible public-benefit costs. Irrigation portions are given special treatment for partial reimbursement. Thus, the power investment includes direct power features and a pro-ration of all other investments which have a dual function. This privilege of cost allocation is only applicable to Federal water-control projects.

It is worth noting that, in very recent years, the use of natural gas in gas turbine power plants has gained considerable favor. Also, there have been some recent installations which use natural gas-fired jet engines coupled to generators in which the waste heat is then utilized for the raising of process steam. A recent installation by Dow Chemical Company in the San Francisco Bay area of California illustrates some unusual features.[17] Three (16,000 Kilowatt) Pratt and Whitney FT4 aircraft-type gas turbines provide a total generating capacity of 48,000 kilowatts, and 450,000 lbs per hour of steam at 150 psig. The gas supply is piped from twenty miles away and is owned by Dow. Power cost estimates run between 3 and 6 mills per kilowatt-hour depending on whether the entire plant is written off in 6 or 3 years respectively. The capital cost for both power and heat-recovery installations is stated at $100 per installed kilowatt. The possibilities of this kind of installation for the North Pacific Country where access might be available to low-priced well-head gas may be well worth investigating. There may be some limiting factors on ambient temperatures.

Present power costs in the North Pacific Country are very high as compared to those attainable in more developed areas to the south. Individual power plants tailored to fit each mining situation will result in all ranges of power costs depending on size of plant, load factor and the cost of fuel. On a system basis, rates for mining could be negotiated, and probably would be more favorable than those representative of average consumption. Table 6 "Some Power Costs in the North Pacific Country" contains data for a number of systems in Alaska, Yukon and Northwest Territory. These are average revenues obtained from sales to small and large commercial and industrial consumers which could include mining

[17] Chemical Week, "Gas Turbines Go One Up," August 6, 1966; Chemical Engineering, "New Gas Turbines Supply the Power and Steam Needs for Ten Plants," August 1966; Chemical and Engineering News, "Dow Uses Jet Engines for Power," August 8, 1966; Diesel and Gas Turbines Progress, "Dow Chemical's 48,000 KW Turbine Installation," August 1966.

operations. It should be noted that dealing with averages can be misleading and also, that the Alaska costs reflect very low fixed charges due to the Federal source of rural electrification funds.

In terms of near-future developments for power supplies two of the Alaska power systems are adding major generation. The Chugach Electric Association, Inc., of Anchorage and environs is in the process of constructing a gas-turbine installation at Beluga, on the north shore of Cook Inlet which should be on the line this year. Chugach has entered into a contract for well-head gas from a group composed of Standard Oil of California, Shell Oil and Atlantic-Richfield. The initial price on gas is 15.2 cents per million Btu's which is roughly equivalent to 1½ mills per kilowatt-hour for fuel costs. The first two units of generation will be each 16,000 kilowatts with an eventual total of 100 megawatts. Transmission will be at 138 KV including a crossing (across Cook Inlet into Anchorage) using four 22,000-foot specially trenched cables. The investment for this initial generating plant, transmission and appropriate substations will be about $12 million. It is hoped that, during the next five years, blocks of 5 to 10 megawatts high-load factor (50 to 80%) power can be made available for 9 to 11 mills per kilowatt-hour although this is still speculative.[18] The Golden Valley Electric Association, Inc. of Fairbanks and environs is also in the process of constructing a mine-mouth coal-fired steam electric plant at Healy. This plant will be fed from coals of the Healy Creek and associated seams. The initial installation will consist of a single 22 megawatt steam-electric turbine with a pulverized coal plant. The plant should be on the line this year. The second unit, probably 44 megawatts, is scheduled for installation and completion in 1970 or 1971. It is stated the site could accommodate as much as 200 to 300 megawatts based on available coal reserves and cooling water capabilities. The delivered price on coal will be about 30 cents per million Btu's for annual amounts ranging from 75,000 to 105,000 tons. The power plant's output will be transmitted about 120 miles to Fairbanks over a single circuit 138 KV line. The total investment in power plant, transmission and substations is estimated at close to $15 million.[19] No estimates are yet available on what power costs might be for large blocks. However, the fuel cost is roughly 3 mills per kilowatt-hour.

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[18] Private communication, from Mr. L. J. Schultz, general manager, Chugach Electric Association, Inc., Anchorage, Alaska, Feb. 28, 1967.

[19] Private communication, from Mr. H. C. Purcell, general manager, Golden Valley Electric Association, Inc., Fairbanks, Alaska, Jan. 27, 1967.

TABLE 6.—SOME POWER COSTS IN THE NORTH PACIFIC COUNTRY

Name of system/plants	Size kilowatts	Type of generation	Miles of line in system (total)	Cents per kilowatt-hour average revenue of commercial and industrial consumers[1]
Alaska:[2]				
Matanuska-Palmer	460	Diesel	674–766	3.09– 3.92
Unalakleet Talkeetna	800	do		
Eklutna, Bureau of Reclamation[3]		Hydro		
Kodiak	7,310	Diesel	41–46	3.73– 5.91
Golden Valley-Fairbanks	9,500	Steam	693–795	3.44– 6.04
Nanana and Healy (under construction—mine mouth).	10,660	Diesel		
	485	do		
	22,000	Steam		
Chugach-Anchorage	14,500	do	591–778	2.06– 2.91
Homer Cooper Lake	1,450	Diesel		
Bernice Lake International	15,000	Hydro		
Beluga (under construction at gas field)	7,500	Gas turbine		
	24,500	do		
	32,000	do		
Naknek	1,550	Diesel	34	7.70– 8.83
Annette-Metlakatla	3,000	Hydro	25	3.46– 3.65
(Purple Lake hydro)—diesel under construction	1,500	Diesel		
Kotzebue	1,400	do	3–6	7.20– 8.28
(Under construction)	1,000	do		
Copper Valley-Glennallen	2,394	do	130–147	7.41– 8.94
Mineral Creek (under construction)	1,800	do		
Dillingham-(Nushagak)	850	do	50–51	5.81–10.15
(Under construction)	500	do		

Name of system plants	Size, kilowatts	Type of generation	Miles of line in system (transmission)	Cents per kilowatt-hour as indicated
Yukon:[4]				
White Horse–NCPC[5]	11,250	Hydro	5	1.25 for retail distribution.
Mayo Hydro–NCPC	5,100	do	35	2.
Porter Creek Hydro / McIntyre Creek Hydro } HY[6]	1,650	do	15	Probably 1.
Northwest Territory:				
Snare Rapids Hydro–NCPC[2]	7,000	do	100	Mining 0.85.
Snare Falls Hydro–NCPC[2]	7,000	do		Others 1.
Taltson River–NCPC[2]	18,000	do	175	Mining and wholesale 1.5. Retail 2 to 5.4
Inuvik–NCPC[2]	3,500	Thermal		Retail 4.5 to 7.
Fort Simpson–NCPC[2]	1,075	do		Retail 5 to 8.
Frobisher Bay–NCPC[2]	4,000	do		Retail 5 to 7.

[1] Range of average annual revenues for customers classified in this category—including small and large.
[2] All systems are rural electric cooperatives using U.S. Rural Electrification Administration funds. Data from USREA Annual Statistical Reports, 1965–63, and other publications.
[3] System in Matanuska Valley supplied from U.S. Bureau of Reclamation Eklutna hydro plant with 2 15,000-kilowatt generators.
[4] From communication Jan. 16, 1967, Hon. Arthur Laing, Minister of Indian Affairs and Northern Development.
[5] Northern Canada Power Commission.
[6] Yukon Hydro Co.

The foregoing two examples embody a relatively initial high investment per kilowatt for total plant. The incremental costs for adding generator should ultimately result in a lower total unit cost. The so-called Alaska "differential" takes its unfortunate toll.

None of the systems briefly described is integrated except for rather limited areal coverage. For example, there is no integration between the systems in Fairbanks and Anchorage areas. Some calculations made some years ago for the Railbelt showed possible savings on the order of at least 10% by the coordination of generating and market diversities, and the possible use of hydro in the Anchorage area for peaking the entire system.

Thermal Energy (Nuclear)

The sudden upsurge in orders for large nuclear power plants throughout the world has outstripped all former estimates. In the United States, estimates of the U.S. Atomic Energy Commission were revised upward twice since 1962 and are now being revised again. In 1962, a 1980 target of 40,000 megawatts was indicated. In 1964, it was revised to 90,000, and this year, the estimate is around 110,000 megawatts with indications this will be too conservative.[20] Although varying estimates are made of world nuclear power growth, they too show enormously fast increases.

In the United States, as of March 31, 1967, there were 14 power reactors in operation with a total capacity of 1,881,200 kilowatts, or an average per plant of around 135,000 kilowatts each. 13 plants were under construction with a total capacity of 7,359,200, or an average size per plant of 570,000 kilowatts. 32 plants were under active planning consideration with a total of 22,906,600 kilowatts or about 720,000 kilowatts average. All of these plants total 32,147,000 kilowatts.[21] Outside of the tremendous jump in numbers and total capacity of plants, it is significant that the average plant size has moved to the 700 megawatt level. New plants recently announced for construction are close to and above the 1,000 megawatt size. However, it should be pointed out that as of today, plants in operation range from the 11,400 KW plant of the City of Piqua, Ohio to 270,000 kilowatts for the Buchanan plant (in New York State) of Consolidated Edison Co. The Hanford dual-purpose reactor at Richland, Washington of the Washington Public Power Supply System, is rated at close to 800,000 kilowatts.[22] This plant was part of the so-called Hanford Atomic Works and, outside of the ore conventional steam-turbine power plant end, is an adaptation of the plutonium processing phase.

Projected investment costs, and I stress the word "projected", now begin to look very attractive. The investment per kilowatt is now reported ranging between $104 to $136 at Oyster Creek No. 1 (605–640 megawatts) of Jersey Central Power and Light Co. now under construction, to $116 for the announced T.V.A. plant with a net capacity for 2,129 megawatts (in two units).[22a] These investment costs are very close to those for similarly-sized coal-fired steam electric plants.

By the same token, "projected" costs per kilowatt-hour are startling. The Oyster Creek estimates are between 3½ and 4.62 mills per kilowatt-hour. See Table 7 "Recent Nuclear Power Economic Analysis—Oyster Creek." The T.V.A. estimates get as low as 2.39 mills per kilowatt-hour.[2] See Table 8 "Energy Cost Comparison of Coal-Fired and Nuclear Plants—TVA." These ranges are not strictly comparable inasmuch as T.V.A. costs of money are much less than those of the privately owned utility. Also, it appears there are some items of cost not included which might bring the T.V.A. estimate somewhat higher than previously stated. But, a candid appraisal leads on to the conclusion that, for plants in the 1,000 megawatt range, the theoretical possibilities for 3 to 5 mill power at the plant's bus are probably reasonable. Again, I have interjected the word "theoretical" for the simple reason that no plant has yet been built and operated in the capacities indicated. It is quite a jump to design, construct and put into satisfactory operation a 1,000 megawatt installation when our actual experience to date has been on the order of less than 300 megawatts.

Although it is virtually unpatriotic to be skeptical about large-scale nuclear power at this time, there are a number of very grave questions to which answers are not clear. Frankly, we are being pushed awfully fast by the nuclear power enthusiasts in government and industry. This does not imply that we should grind to a halt while seeking answers: It does mean we should slow down a bit, and particularly avoid putting all of our electrical power eggs in the nuclear basket. Prudence dictates further major expansion in the use of fossil fuels and large hydro if for no other reason than to provide some insurance against existing and other problems to which solutions may not come as fast as the nuclear enthusiasts would lead us to believe. The argument that we must risk many things for the only sake of a low power-price is nonsense, if not irresponsible.

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20 Tremmel, Ernest B., Director, Division of Industrial Participation, U.S. Atomic Energy Commission, "Challenges in the Electric Power Field," before Southeastern Electric Exchange, Boca Raton, Fla., Mar. 22, 1967.

21 By U.S. Atomic Energy Commission Release No. IN–778, "Status of Nuclear Power Plants as of Mar. 31, 1967," Apr. 10, 1967.

22 Ibid., footnote 3, page 27.

22a Based on private financing fixed charges of 13.5 percent.

TABLE 7.—*Recent nuclear power economic analysis—Oyster Creek (adapted from source*[1]*)*

Type of reactor: Boiling water.	
Capacity, kilowatts	605,000
Investment (dollars per kilowatt):	
Direct	$117.00
Estimated overhead and contingencies	19.00
Total investment	136.00
Energy cost (mills per Kwh):	
Capital costs[2]	2.62
Fuel costs	1.45
Operation and maintenance (including nuclear insurance)	.55
Total	4.62

[1] U.S. Congress, Joint Committee on Atomic Energy, 88th Cong., second sess., committee print, "Nuclear Power Economics—Analysis and Comments—1964," Washington, D.C., 1964, p. 8.
[2] Based on private financing fixed charges of 13.5 percent.

TABLE 8.—ENERGY COST COMPARISON OF COAL-FIRED AND NUCLEAR PLANTS—INITIAL 12-YEAR PERIOD (ADAPTED FROM TVA REPORT)[1]

Item	Location and type		
	Browns Ferry, Tenn.		Cumberland, Tenn., coal fired
	BWR	PWR	
Net plant capacity kw	2,129,000	1,989,000	2,206,000
Investment dollars/kw	116.0	121.3	117.0
Transmission dollars/kw	1.4	1.5	6.0
Energy cost mills/kwh			
Interest and depreciation on plant investment[2]	.89	.93	.90
Fuel cost	1.25	1.39	1.69
Operation and maintenance	.19	.18	.24
Nuclear insurance	.04	.04	----------
Total bus-bar cost	2.37	2.54	2.83
Interest and depreciation on transmission investment	.01	.01	.05
Transmission losses and O. & M	.01	.01	.02
Total cost	2.39	2.56	2.90

[1] Office of Power, Tennessee Valley Authority, Chattanooga, Tenn. "Comparison of Coal-Fired and Nuclear Power Plants for the TVA System," June 19 6.
[2] Based on sinking fund depreciation for 35 years and 4½ percent interest public financing.

Note: BWR: Boiling water reactor. PWR: Pressurized water reactor.

The problems which exist regarding the race for bigger and more nuclear power are at least three:

1. The problem of assured operational reliability in large plants.
2. The problem of nuclear waste disposal.
3. The problem of sufficiency in nuclear fuel on the basis of present and anticipated assured technology.

Little is said about the first problem. However, most engineers realize what size means in complexity and reliability, especially if construction and operational experience is lacking. The power economists know what a shutdown for a mammoth plant means in terms of cash-flow. This is probably the least important of the three problems, but the experience with the Apollo space-program dramatizes the fact that expenditures of huge sums of monies do not always guarantee reliability, let alone safety. Just imagine the tremendous burden and responsibility placed on manufacturers in the mad, mad rush to build more and more of these complex reactors.

The present types of reactors produce a certain amount of radioactive substances which are wasted. These are so deleterious and long-lived that, as yet, the only solution to disposal is to bury them. The quantities of such wastes as more and more nuclear capacity is placed in operation pose a major ecological problem. Work is being done on various methods for disposing of the wastes including possible pumping into deep limestone strata of the lower earth mantle. However, no rational nuclear engineer or administrator is very happy about the situation.

The most significant immediate problem relates to the adequacy of uranium reserves as the basic fuel for nuclear reactors now contemplated. The problem is recognized although for awhile, it was swept gently under the rug. For instance, A.E.C. Commissioner Wilfred E. Johnson on April 10, 1967[23] said the following: "If, in fact, there should be 110,000 megawatts of capacibility by 1980, the lifetime fuel requirements of the reactors then in place would approximate 500,000 tons, or more than three times presently known reserves of U_3O_8 available at a price of about $8 per pound." He goes on to say, "The hard questions which this statement of the problem raises are two:

"When will the demand for uranium exceed our ability to recover it at a low enough cost to keep fuel cycle costs for a light water reactor from rising excessively?

"When can we expect to have the technology of the fast breeder reactor developed so that we can begin to introduce economic breeder plants into the electric utility industry?

"Unfortunately, no one can answer these questions accurately. Both depend upon how readily nature will yield to the pressures of exploration and technology—areas which provide room for a variety of faiths."

The same problems stated even more forcibly were discussed at length by representatives of Atomics International at a recent Northwest Public Power Association meeting at Wenatchee, Washington, in March of 1967.[24] * * * the nuclear industry is confronted with a paradox wherein its rapid growth rate could give rise to ore shortages which could stifle that growth * * * To some it might seem unreasonable to focus attention upon problems which appear to arise 15 to 25 years in the future. However, when one considers that about 15 years are required for a new reactor concept to mature and that a given plant will have an economic life of 30 years or more, the need for long-range planning is obvious. The rapidly expanding use of nuclear power is building up a momentum in the direction of resource depletion which will be harder and harder to redirect as time goes on. These facts impose an urgency upon the development of advanced systems which can utilize our limited fuel supply more efficiently."

Further, the authors explain: "Ore costs become significant when one realizes that light-water reactor fuel costs could increase about 0.06 to 0.08 mills per kilowatt-hour for each dollar per pound of escallation in ore price. If not compensated by significant reductions in other fuel components, these fuel costs could rise enough to make light-water reactors only marginally competitive with fossil-fueled plants by 1990, or within the operating lifetime of plants currently under construction." The impact of this last statement can be measured quickly. Some believe that the price per pound of uranium fuel (so-called yellow cake) now calculated at $8 per pound might have to rise to around $30 to $32 per pound as an incentive for the use of lower-grade resources. This would mean an increase in the fuel cost ranging anywhere between 1.3 to 2.0 mills per kilowatt-hour or providing a total generating cost of slightly less than 4 to perhaps as much as 6½ mills per kilowatt-hour.

The commonly-used retorts to the problems thus described are fairly standard by now. For example, reference is made to the past alarms which have not materialized about oil and gas resources: how today the reserves appear greater than they were three or four decades ago. The fact that uranium resources are by no means comparable in occurrence to oil and gas reserves is not mentioned. Further, there is much said about the mining industry will come to the "rescue" and will find the ore we need. Reference is also made to the drill cores which have been obtained by the oil and gas industry and which probably include sections of uranium-bearing ore. One wonders whether those who get excited about this realize that the cost of mining only begins upon discovery. In other words, there is a great reliance of faith on finding the yet-unknown.

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[23] Johnson, Wilfred E., "Some Implications of the Fast Reactor Program in the U.S.," before the American Nuclear Society, San Francisco, Calif., Apr. 10, 1967.

[24] Dieckamp, H. M., Falcon, J. A., Hoffman, B. L., "Planning To Meet Tomorrow's Nuclear Needs," Atomics International Division of North American Aviation, Inc., Wenatchee, Wash., Mar. 29–31, 1967.

The other phase of the solution to the problem of fuel resources lies in the development of the so-called breeder reactor. Theoretically, this would provide the answer to depletion of uranium ores. However, on the basis of experience so far obtained, the problems are difficult and costly ones. Commissioner Johnson estimates that: "The investment required to bring into existence a viable breeder reactor capacity having the confident support of industry will likely be at least two billion dollars." Of course, compared to expenditures being made in southeast Asia and for such purposes as the "race to the moon," this is small. The question is partly: "Who is going to foot this developmental bill over and above the Federal government?" More important, however, is no one is yet sure which type of reactor concept should be pursued: liquid-sodium, steam or helium cooled? Liquid-sodium offers many theoretical advantages including the fundamental property of having ten times the heat transfer coefficient of steam or helium. But, as found in prototypes such as the Enrico Fermi reactor which is now inoperative and a problem,[25] a sodium-cooled reactor is tricky to operate. Thus, the lead-time is very considerable. The Atomics International Division group[26] estimate that if demonstration fast breeder reactor construction were initiated in the early 1970s, commercial acceptance might be achieved by the mid 1980s. A total fast-breeder capability of 500,000 megawatts might be achieved just about the end of the century with sufficient plutonium production to assure all new construction thereafter would be fast-breeders.

The foregoing has been recited not in disparagement of the nuclear age, but to bring into focus that it won't all be easy, nor at all assured in the kind of time schedules required. As prudent people, we should make use of assured power-producing devices especially those which depend on renewable resources such as hydro. That is why the Rampart project is needed as rapidly as it can brought into being. There are other North Pacific projects such as the Liard which also need immediate attention.

THE NEED FOR POWER INTEGRATION

The foregoing review has provided some rudimentary information on the water power resources of the North Pacific Country, a hasty look at fossil fuel resources of the area, and has touched on nuclear energy. Table 9 "Tentative Summary of Hydroelectric Potential in North Pacific Country" indicates there may be on the order of 50 million kilowatts at various sites and regions. However, as pointed out, many of these are probably high-cost, with only the Rampart and Yukon-Taiya or Yukon-Taku providing estimated costs in the range of 2 to 3 mills per kilowatt-hour at bus-bar.[27] There are some other individual projects of some size which might provide power costs under 5 mills if they were integrated into a total power system. However, no analyses of any real consequence have yet been made of the overall efficiencies which interconnection might facilitate.

Interconnection or coordination or integration makes use of the somewhat different characteristics of diverse power generation and power consumption which are found in separated areas or regions. For example, hydro systems will be used more and more to supply peaking power to power systems containing a great deal of thermal power base-generation. This thermal generation will contain both conventional and nuclear plants which operate most efficiently at base-load conditions. Seasonal surpluses in northerly hydro systems can be marketed to southerly systems which need the surplus. Such operation permits exchange of energy between regions. This exchange takes advantage of diversity in streamflow (for hydro) and peak-load conditions. In short, an integrated system makes use of all favorable generation characteristics, and molds market conditions to reduce costly peaks. It permits the storage of energy in hydro reservoirs in one part of the system when excess amounts are available elsewhere.

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[25] U.S. Congress, Joint Committee on Atomic Energy, 89th Cong., second sess., hearings, "Enrico Fermi Reactor: Use for Irradiation Testing," Washington, D.C., Apr. 5, 1966.

[26] Dieckamp, H. M., Falcon, J. A., Hoffman, B. L., "Planning Today To Meet Tomorrow's Nuclear Neews," Atomics International Division of North American Aviation, Inc., Wenatchee, Wash., Mar. 29–31, 1967.

[27] These costs do not reflect the costs of fish and wildlife enhancement as estimates to date do not appear to have much relationship to reality or carefully considered facilities.

TABLE 9.—TENTATIVE SUMMARY OF HYDROELECTRIC POTENTIAL IN NORTH PACIFIC COUNTRY [1]

	Major river systems	Installed capacity, in megawatts [2]
Alaska:		
1. Northwest	Noatak, Kobuk, etc	686
2. Interior	Yukon, Tanana, Nenana, etc	17,568
3. Southwest	Kuskokwim, Kvichak, Kijik, etc	2,936
4. South-central	Copper, Susitna, Chakatchatna, etc	8,419
5. Southeast	Many lakes, some streams, including Stikine	2,754
Subtotal [2]		32,383
Yukon and Northwest Territories (Yukon only, "modified" system):		
1. Main stream, Yukon River		2,020
2. Pelly River		434
3. Stewart River		1,001
Subtotal		[3] 3,455
Northern British Columbia:		
1. Northern British Columbia	Including Yukon-Taku diversion	3,930
2. Upper Liard	Liard and parts of Nahanni	2,400
3. Lower Northern Coast	Including Stikine and Iskut Rivers	890
4. Skeena and Nass Basin	Including Skeena and Nass Rivers	1,880
5. Peace River	Upper and Lower Peace River	2,550
Subtotal		[4] 11,650
Approximate grand total order of magnitude for Alaska, Yukon, and northern British Comumbia [3]		47,488

[1] Alaska, Yukon and Northwest Territories, northern British Columbia, north of Prince George.
[2] Installation at 50 percent load factor.
[3] Not strictly accurate due to addition of installed capacity (estimated) and installed capacity estimated at 50 percent load factor.
[4] At 50 percent load factor.

The Pacific Northwest-Pacific Southwest intertie system now under completion makes use of these various advantages. This is accomplished by the world's largest transmission network composed of both 750 kilovolt D.C. and 500 kilovolt A.C. transmission lines extending from the Columbia River to the Los Angeles and Hoover dam areas. Total distances range 800 to 1,000 miles depending on route. The total estimated investment for the transmission system is in the neighborhood of $700 million. Other systems in the United States, as well as in other parts of the world, are either in early operation, in construction or planned. Thus, the principle of manipulating enormous blocks of electrical power over very great distances by very high voltages is a reality.

Experience to date in the intertie briefly described above provides some rough guidelines for the determination of investment for these large transmission lines. Assuming the transfer of very large blocks of power at 750 KV D.C. with terminal converter and inverter stations, an investment of around $160,000 per mile for a "plus and minus" system is probably close to actual at this time under reasonable terrain and climatic conditions. The cost of inverter and converter stations will probably run between $20 to $25 per kilowatt of capacity.

There are, however, a number of conditions which fundamentally affect the development of an integrated system in the North Pacific Country. First of all, such a system cannot be accomplished piece-meal: it must be part of an overall interregional plan. This plan should include the consideration of points of major generation together with centers of heavy consumption also at various points along the system. Such a system would be designed to shift or displace blocks of power along the transmission and generating route, and to make large blocks available for consumption at various points. In other words, it is not necessary to consider the massive movement of large blocks all the way from the most northerly point of the system to its southernmost extremity although this could be done.

The combination of generating and consuming points along such an enormous system presents a "chicken and egg" problem. But, it is not beyond accomplishment provided all hands can get together in some sort of homogeneous organization.

On the one hand, there are at least three anchor points where massive generation from hydro would be available. This would include, in a southeasterly direction, Rampart (approximately 5 million kilowatts), Yukon-Taiya/Taku (between 2½ and 3 million kilowatts), the Liard system (about 3 to 4 million kilowatts), the Peace River complex (about 2½ million kilowatts), and thence to the Columbia River power generating systems both in Canada and the United States. There would be also a number of fossil fuel reserves for possible very large thermal power plants. The distances between these major points of generation would range between 500 to 800 miles, well within conservative transmission line capabilities. However, to provide maximum system efficiencies and stability, the development of major power consuming loads at or near these points of generation would be of great help in facilitating reaching lowest total power costs.

If one examines the approximate route which the foregoing system might take, it is interesting to note that within reach of the system at least in the Canadian region, there are very great potentials for a variety of industrial minerals. In some instances, development and operations are already in full swing. In others, the rendition of values will depend on two alternatives or their combination. The first entails the provision of transportation to tide-water or to established rail-head. The second would provide the processing at or near the mine to reduce the volume of material to be shipped. The processing might utilize the electrolytic cell or the electric furnace (See Table 1 "Electroproducts, Raw Materials Power Requirements and Characteristics").

By way of example, the excellent occasional reviews by John Dawson of B. C. Hydro and Power Commission on the mining industry of British Columbia and the Yukon [28] point to some specific items. In the overall complex of silver-lead-zinc properties (which might be amendable to electrolytic processing), there are the mining properties of United Keno Hill (Falconbridge), Dynasty (Cyprus), Kerr-Addison Mines, Norquest. Going down into British Columbia, there are the New Taku, Erickson-Ashby, Ventures near Cassiar, Silbak-Premier, Noradco, Cassiar Consolidated, Dolly Warden, New Cronin-Babine, Hudson Bay Mtn. Silver. Principal copper properties along or near a potential route for the power system for possible electric smelting are such as New Imperial, Julian Mining, MacIntyre-Porcupine, Silver Standard of AS & R, Stikine Copper of Kennecott, Granduc of Newmont-Hecla, Croydon of Rio Tinto, Carlisle and Chattaway. In iron properties, there are, of course, the intriguing Yukon reserves of Crest Exploration. Whether additional properties would come to light if adequate power supplies for electric furnace smelting were available is conjectural but worth thinking about. The molydenum properties which might furnish material for electric furnace processing include Cominco, near Atlin, Yukon, and the cluster ranging around Stewart, B.C. in a southeasterly direction toward the Prince George area. Properties there include the Newmont, B.C. Molybdenum, Amax Exploration at Hazelton and near Smithers, American Metal Climax, Phelps Dodge, United Buffaddison, Endako of Canadian Exploration, Copper Ridge and the Julian Mining.

The foregoing, obviously, is only exemplary. It is also undoubtedly very incomplete of potentials which, as pointed out, might be stimulated by the availability of large blocks of low-cost power. As is well known throughout the world, such availability has invariably resulted in the development of mineral and other industries.

With regard to Alaska, and more specifically the Rampart project, the comprehensive analyses of Development and Resources Corporation,[29] concluded a number of electroprocess industries could be established in Alaska at tidewater to utilize the entire output of the project if it were available.

As previously intimated, the system so sketchily outlined would be a part of a larger system covering the entire West Coast. Reaching from the Far North to the Far South, it would include two time-zones and a tremendously diverse range of both power generation and consumption patterns. The potential for power integration and manipulation is exciting: the potential for the resulting development of the North Pacific Country even more so.

There are many who, for a wide variety of reasons, oppose various phases of this overall development. Most of them have taken emotional rather than factual positions which fail to recognize the overwhelming fact that the overall benefits far outweigh the disadvantages. Those who envision the development of our

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[28] British Columbia Hydro and Power Authority, Industrial Development Department, "The Mining Industry of British Columbia and the Yukon," second edition, January 1966, Vancouver, B.C.

[29] Development and Resources Corporation, "The Market for Rampart Power, Yukon River, Alaska," for the U.S. Corps of Engineers, U.S. Senate Committee on Public Works, 1962.

vast North Pacific Country to provide many urgent necessities for the growing North American population will eventually outvoice the shrill opposition. When all is said and done, as Senator Ernest Gruening of Alaska has stated so well, "homo sapiens" counts too.

The job will be a tremendously complex and difficult one to organize and start. However, it will take the boldness which has been so admirably demonstrated in British Columbia by its Premier and the Crown Corporations dealing with power and transportation development. It will take organizational patterns not greatly different than those used in the Tennessee Valley. It might embody some portions of the North American Water and Power Alliance concept. What was accomplished in very recent years by Premier Bennett of British Columbia and Mr. Charles Luce (now U.S. Undersecretary of the Interior) is token of the fact that such complex tasks can be accomplished if the objectives are clearly and forcefully defined. It may take some doing, but it's worth the doing.

[From Outdoor Life, November 1968]

Danger! Heat Kills Rivers, Too

(By Ivan Bloch and Ben East)

Listen, sportsmen, and listen carefully. If you are concerned about the future of water and all the uses and pleasures that go with it, there is a new headache that you had better be keeping an eye on. It's a headache that will get a lot bigger before it's cured.

A serious threat, heretofore almost unheard of and largely ignored, hangs today over every major river, many of the big lakes and impoundments, and even the ocean estuaries of this country.

Water has been polluted in the past. Lakes have been killed by sludge from industries and cities, by mine drainage, by the poisons of pesticides. Rivers have been fouled, dammed, drained for power and irrigation. Some of our finest waters have been left devoid of fish and unfit for boating or camping, their beaches even made unsafe for swimming.

Now, to the long list of abuses that have done such shameful damage, something new is being added.

It is heat. Heat in the form of hot water that, unless preventive steps are taken, will be poured out from huge thermal-nuclear plants generating electric power. Only recently has the public begun to hear of this threat, but it is fast taking its place among the grave conservation problems confronting the nation.

Conservationists have a name for this inflow of hot water. They call it thermal pollution, and biologists warn that it can alter drastically the character of a body of water, even one as big as Lake Michigan.

In most cases the power interests wince at that name and that forecast.

"I think we have been foolish," says a New Jersey utility executive, "to let the conservationists saddle us with the term thermal pollution. Why not call it thermal enrichment instead?"

Whatever you call it, it is a problem that now confronts much of the U.S. and is growing at a staggering rate. Last June the Atomic Energy Commission issued a map that showed a total of 102 nuclear power plants in the country—15 in operation, the rest under construction or planned for the immediate future. This was an increase of 30 plants in nine months. And the map falls far short of telling the whole story since many of the proposed plants that are worrying sportsmen do not appear on it, because permits to build them have not yet been applied for.

The 102 plants shown on the map are scattered in 28 states in every section of the country except the Rocky Mountain region, where there is only one, in Colorado. This is only the beginning of a rapidly developing pattern that is bound to cover all parts of the nation in 20 to 30 years.

The production of kilowatt-hours is soaring by the billions, and so is the need for water used for cooling in the thermal pla·ts that produce the power. The Sport Fishing Institute predicts that by 1980 those plants, many of them huge and nuclear-operated, will require 200-billion gallons of water per day, most of it for cooling.

The process—known as once-through cooling—consists in taking cool water from a river, lake, or estuary, pumping it through the plant to cool the turbines, and returning the then-hot water to its source.

The 200-billion gallons a day that the Sport Fishing Institute says will be needed in another 12 years is one-sixth of the country's total average runoff. And since much of the runoff occurs in times of flood flow, for the remaining eight months of the year something like half of the total run-off will be needed for cooling purposes. Even more ominous is the fact that in certain heavily populated and industrialized states, the *total* flow of the rivers involved may have to be passed through the cooling systems of power stations.

Add to that gloomy forecast the claim by engineers that, by the year 2000, power plants will be giving off nine times as much "waste heat" (the engineering equivalent for thermal pollution) as they do now, and you get some idea of the magnitude of the problem.

What will the consequences be? What will happen to a river as big as the Columbia, or to the far smaller Connecticut, if such huge amounts of hot water are dumped in? What will happen to Lake Champlain or Lake Michigan, or even to Chesapeake Bay or the estuaries along the coast of California? How much harm will be done?

There is disagreement on these questions, even among the experts. But many responsible authorities are hoisting storm warnings.

Last February the U.S. Senate Subcommittee on Air and Water Pollution held a series of hearings on thermal pollution. Its chairman, Senator Edmund S. Muskie of Maine, now the Democratic candidate for Vice President, announced that the hearings would probe "the known effects and, perhaps more important, the unknown effects.

"It is obvious from the limited information we have that we cannot allow this situation to continue," Senator Muskie concluded.

Dr. F. J. Trembley, professor of ecology at Lehigh University, puts it this way: "To avoid disaster, we must know where we are headed."

As of today, the tone of forecasts on the results of a nationwide outpouring of hot water depends largely on who makes them.

For the most part, spokesmen for the power interests—except where they have been called sharply to account by conservationists or state authorities—are disposed to minimize the threat or shrug it off. In a few cases, they say quite frankly and a bit scornfully that they put power ahead of fish.

"Until recently the power industry has operated with little regard for the environment," commented one witness before the Muskie hearings.

Scientists who study man's environment and its effects on him take a dimmer view, and so do public officials who deal with water quality, fishing and outdoor recreation in general. They warn that if thermal pollution on such a huge scale is tolerated, we must expect the worst.

For example, a leading ecologist at a Midwestern university told OUTDOOR LIFE that even a river the size of the Ohio does not have enough water to cool the output of any large number of nuclear plants. And in southern California, a committee of scientists recently called for a one-year moratorium on all nuclear power plant sites, until a complete study of the coastal waters can be finished.

"Thermal pollution at its worst must take its place along with toxic chemicals, toxic metals, oil pollution, pesticides, and other waste materials that pose increasing threats to our natural resources," Ronald Green, commissioner of the Maine Department of Sea and Shore Fisheries, told the Muskie hearings late February.

"Large volumes of heated water may be detrimental to fish, not only directly but also indirectly, through changes affecting food organisms," warns the U.S. Fish and Wildlife Service.

And the Sport Fishing Institute sums it up this way: "The heat factor controls aquatic life."

Last year for the first time, the discharge of hot water from power plants was listed as a known cause of fish kill in the annual report, "Pollution-Caused Fish Kills," put out by the Federal Water Pollution Control Administration.

The Congressional Record for November 30, 1967, carried a sweeping indictment, reprinted from a Pennsylvania paper, of the consequences of thermal pollution:

"It takes about a kilowatt of power to run a small kitchen appliance such as a toaster," Gary Brooten had written in the Philadelphia Sunday Bulletin. "For every minute that toaster toasts, a gallon of water has to swish through the cooling system of a power plant. When it gushes out it is 10° to 20° hotter than when it went in. When gallon follows gallon up into the millions, fish die, lose interest in reproduction, or are unable to migrate to spawning areas. Trout eggs will not hatch. Weeds thicken, and odors develop if the heat is great enough."

Representative John Saylor of Pennsylvania thought enough of Brooten's article that he had it included in the Record, coupled with a vigorous statement of his own on what he called "ruinous thermal pollution of streams."

There are ways to avert this ruin. The water used in cooling can be cooled in turn, by passing it over huge ventilated towers.

The cooling systems fall into two basic types: open-circuit and closed-circuit.

In the open-circuit type, the water is pumped to the top of the tower, flows down over baffles and is then returned to its source at a temperature low enough so that it will do no harm.

In the closed-circuit system, water is cooled and then reused, over and over, much as in a car radiator.

The open system is cheaper but has disadvantages. About 20 percent of the water is lost through evaporation, and fog and ice are likely to develop as side effects.

"In winter," an engineer says of the open-circuit system, "All at once there may be an area of several square miles where everything is covered with sheet ice. Or on a beautiful summer morning you may drive over a hill and find yourself in pea-soup fog such as you have never seen before."

Even those who dwell on these drawbacks, however, cannot explain the fact that open-circuit cooling towers have been used in Europe for many years without out arousing serious objections.

The closed system is more costly partly because of power required to drive the giant fans—up to 30 feet in diameter—that cool the water.

And in either system, of course, the towers add to the cost of construction. A proposed plant on the Maine coast, for example, is to cost $130-million and towers would add $5-million to $10-million to that figure. For a plant on the Connecticut River, the cost of installing and operating an open-circuit system is estimated at $800,000 a year, a closed-circuit system at $2.3-million. The lower figure would mean an increase of one percent in power rates that the consumer would have to pay, the higher figure just under three percent.

Says one engineer who has made a careful analysis of the cost of installing and operating cooling systems, "You'd have to stretch and strain to arrive at a figure of three-percent increase in power price for a tower-equipped plant over one without towers."

The towers have one other drawback. They are huge, and some people regard them as unsightly. A recently completed cooling system in Pennsylvania has the biggest such towers in the world. They are 370 feet high (taller than a 30-story building) and 380 feet in diameter. Such structures would hardly be welcome in places concerned with scenic beauty. If towers are properly designed and located, however, much of this objection can be avoided.

There is another way to escape the consequences of thermal pollution. That is to dissipate the waste heat by the use of big cooling ponds of up to 1,000 acres each, isolated from streams or lakes. The water could either be reused or returned to its source after it has cooled.

To date, the power companies have shown little voluntary interest in cooling systems, for reasons of cost. It is, of course, cheaper for the companies to take cool water at virtually no cost and dispose of it by returning it, hot, to its source. But as the Nuclear Technology Institute of White Plains, New York, points out, "The cost to society of environmental changes caused by thermal wastes is unknown."

So, although reliable ways of avoiding thermal pollution are known, the utilities building the giant nuclear plants of the next 20 years are not likely to spend the money unless they are forced to.

Who will set up and enforce the necessary regulations? That is the crucial question today.

It's hardly a job for the states, since in almost every case the rivers and lakes big enough to provide the nuclear plants with the water they require extend across state lines. Interstate compacts may help, but conservationists generally agree that regulation must come from the federal government.

And to the dismay of state officials, sportsmen, and even members of Congress, the Atomic Energy Commission—which licenses all nuclear plants—has taken the flat position that it has the duty only to guard against radioactivity, and that thermal pollution is none of its concern.

Says Senator Muskie bluntly: "Federal agencies are not assuming a proper leadership role. Often their activities actually condone pollution."

Legislation now before Congress would charge the Atomic Energy Commission with specific authority to control thermal discharges from nuclear plants. And a bill introduced by Representative John Dingell of Michigan would give the Secretary of the Interior control over such discharges.

Clearly, some branch of the Federal government must be given such authority and goaded into firm action before the nation plunges further into the era of nuclear power.

Nowhere is the problem being debated more heatedly right now than in the Pacific Northwest, where the sport and commercial fisheries of the Columbia River, worth an estimated $14-million a year, are threatened. The hot-water controversy there is itself at the boiling point. Sportsmen, conservation leaders, and state and federal pollution officials are arrayed on one side, power interests and a few government officials on the other.

Speaking before the Oregon Division of the Izaak Walton League at Portland last February, Richard F. Poston, the regional director of the Federal Water Pollution Control Administration, sounded a hard-hitting warning:

"Nuclear power development," he said, "presents the greatest single threat to the fisheries and the environment that we face in the Pacific Northwest in the next few years. Once-through cooling on cold-water streams will not be possible for new plants."

At the same meeting George Snyder, a fishery biologist for the U.S. Fish and Wildlife Service, took a look into the future and came up with some very disquieting forecasts.

"In 1966 the largest nuclear electric plant in the United States went into production in eastern Washington, at Hanford on the Columbia River," he reminded the Ikes. "Its cooling system pumped 1,240 cubic feet of water per second, raising the temperature some 30°. That was more than is used daily in the entire state of Texas for its domestic supply.

"A recent 20-year plan of power development announced by the Bonneville Power Administration calls for the installation of 20 new nuclear plants in the Pacific Northwest, and six more by 1990. The water needed for each will be 2,000 cubic feet per second, and it will be heated 16°."

Snyder then analyzed the effect on fish runs, chiefly those of salmon, shad, and sturgeon, in the Columbia.

"The temperature increase in the thermal plumes can affect any fish moving up or down the river, regardless of size," he warned. (A thermal plume is the name given to the stream of hot water that gushes from the cooling outlet and carries downstream until it is diffused in the cooler water of the river.) In the nuclear plants on the Columbia, the discharge tubes would be 11 feet in diameter.

"The subtle increase in total river temperatures may not be so subtle when compounded by low flow and tidal fluctuation," Snyder concluded.

Carl Elling, director of the U.S. Fish and Wildlife Service's Biological Laboratory at Seattle, makes a prediction that is even more grim.

"The salmon of the Pacific Northwest," he says, "are on their way toward joining the dodo if nuclear power plants are allowed to use the rivers to operate their cooling systems."

The Sport Fishing Institute backs Elling this way:

"If all river development now contemplated for the Columbia basin should materialize, along with the predicted rise in water temperature, the consequence would be the total extirpation of that great river's anadromous-fishery resource."

To date, much of the controversy in Washington and Oregon has swirled around plans of the Portland General Electric Company to build a 1-million-kilowatt plant at Trojan, 70 miles above the mouth of the Columbia, and plans for a plant to be built by two public-utility districts on the Washington side of the river six miles farther upstream.

These two plants are planned for the near future and have prompted the Federal Water Pollution Control Administration to announce that permits for both will be refused if their hot water is to be returned directly to the river.

The Oregon Sanitary Authority is on record as refusing to allow the discharge of heated water into any river in that state.

"If building a cooling tower makes a nuclear power plant impractical, then the power companies will have to find other sites," says the Sanitary Authority's chairman, John Mosser.

Last July many salmon died in the Columbia downstream from the recently completed John Day Dam, and biologists ruled that the kill probably was caused by excess nitrogen in the blood of the fish (a situation that accounts for "bends" in human divers). But Federal Water Pollution Control Commissioner Joe G. Moore was quick to point out that any increase in water temperature would compound dangerously the effects of high nitrogen levels. In other words, the kill last summer would almost certainly be a forerunner of far-bigger kills if the river is polluted with hot water.

As hot as the issue of thermal pollution is in that part of the country, it is no less so in New England, where nuclear plants are already in operation in Massachusetts and Connecticut and others are under construction in Massachusetts, Vermont, Connecticut, and Maine. All are projects of four closely affiliated atomic power companies—Connecticut Yankee, Vermont Yankee, Massachusetts Yankee, and Maine Yankee.

The proposed plant at Vernon, Vermont, on the Connecticut River south of Brattleboro, has created the sharpest controversy. The Wiscasset plant on the Maine coast at the mouth of the Sheepscot River also is causing concern.

Original plans of the Vernon plant, a Vermont Yankee project, called for using two-thirds of the total flow of the Connecticut for cooling, and returning the water to the river 20° hotter than when it was removed.

In "New Life for An Old River," in OUTDOOR LIFE last June, Ted Janes told of a four-state project (New Hampshire, Vermont, Massachusetts, and Connecticut) to restore shad and Atlantic salmon runs to the Connecticut. Fish-and-game departments of the four states believe that spawning runs of 2-million shad and 38,000 salmon can be achieved.

But Janes warned that the Vernon nuclear plant might create a hot-water barrier through which migrating fish could not pass, and so doom a sport fishery conservatively estimated to be worth $1.6-million a year in cold cash. He reported the Atomic Energy Commission's ruling that thermal pollution was none of its affair, and he told of threats of injunction proceedings by the states concerned.

Vermont Governor Philip Hoff, testifying before the Muskie hearing last February, describing efforts made by his state—efforts in which New Hampshire, Massachusetts, and Connecticut joined—to block damage to the Connecticut. Hoff angrily criticized the Atomic Energy Commission for its refusal to consider the threat of thermal pollution.

"With that decision, A.E.C. declared itself a publicly financed lobby indifferent to the public interest," the governor charged. "The nuclear power industry may be in its infancy, but its potential for harm is fully matured."

The Vermont Yankee dispute promises to have a happy ending, however. Toward the end of 1967 the utility changed its position and agreed to build cooling towers, at a cost of $6.5-million, to avert the hot-water damage.

Meanwhile, this newest threat to fishing and water quality is becoming an almost equally critical issue in many other parts of the country. For instance, the National Wildlife Federation recently reported plans for a nuclear plant on Cayuga Lake, in the Finger Lakes region of New York. The plant would take in 500,000 gallons of water a minute and heat it 20° to 25° before returning it to the lake. The discharge of hot water every 24 hours would be sufficient to cover the entire lake with a one-inch layer.

[In September the New York State Atomic and Space Development Authority announced plans to record heat patterns in the state's major waterways with the object of determining where to place nuclear power plants so that the large quantities of hot water they discharge will not "upset the balance of nature or damage waterlife."

An infrared mapping device, carried by an airplane, scans the landscape below and detects infrared rays given off in varying intensities by all warm objects. Through a complicated process, the heat patterns are traced out on photographic film, and the resulting print, in most respects, resembles an ordinary photograph (see pages 45 and 130). The key difference is that hot objects look white, cold ones look black, and those of in-between temperatures show up in various shades of gray.]

In a body of water as large as Lake Michigan, there would seem to be little cause for worry about thermal pollution. Lake Michigan is the second-largest of the Great Lakes. It is more than 300 miles long and 100 feet wide, with a maximum depth of 923 feet. It's hard to imagine enough hot water being poured into such a giant to do damage.

Michigan's top conservation authorities, however, are far from unconcerned. At a conference on Lake Michigan pollution, held in Chicago last February, Dr. Ralph MacMullan, director of the state's Department of Conservation, warned that the consequences may be more than are bargained for.

"Production of nuclear power is expected to increase 61 times in the next 12 years," he said. "By the mid-1970's we may have 10 or more giant nuclear stations on the shores of Lake Michigan. Two are already turning out power. One would use half a billion gallons of water a day and heat it 28°.

"As a biologist," MacMullan continued, "I can predict with confidence that any permanent warming of Lake Michigan, even if very slight, will have widespread effects. It will make the lake uninhabitable for some organisms now present, habitable for others not found there now. If we have problems with algae on our beaches at present—and we do—we will have bigger ones with the addition of heat. It has even been predicted that any considerable warming of Lake Michigan could result in changing the climate of Michigan, perhaps by doubling or trebling snowfall."

Even in the case of ocean estuaries, all the evidence hints that the long-range consequences of hot-water pollution may be disastrous.

"The living resources of the sea seem delicately responsive to minute changes in their surroundings," warned the National Academy of Sciences.

The Wiscasset plant of Maine Yankee will be located on Montsweag Bay, an estuary of the Atlantic. The hearings before the Muskie committee on this site brought firm warnings that the contemplated discharge of 656-million gallons of hot water a day can have serious effects.

"It is unthinkable to build a bridge or license an antibiotic without a safety factor," one expert told the committee. "We need safety factors in water-quality standards as well."

The bitterest argument to develop to date around an ocean site involves the $22-million plant planned by Florida Power and Light Company on Biscayne Bay, 30 miles south of Miami. Plans call for the discharge of almost 2-million gallons of heated water a *minute*, the equivalent of 1,800 acres four feet deep each day. The average depth of the bay is only seven feet.

Florida conservationists are fighting tooth and nail against what they fear will prove the total ruin of the bay, which provides from 500,000 to 1-million man-days of sport fishing a year. The Sport Fishing Institute labels the proposed circulation of hot water "a serious threat to the marine life, commercial fisheries, and recreational use of the area."

In Chesapeake Bay, concern is growing that thermal pollution may damage major spawning grounds of striped bass. Plans are afoot to build a number of nuclear power plants there.

"The bay is of enormous value to Maryland and to the nation," a scientist recently pointed out. "No major change should be made in such a region until reliable estimates can be made of the gains and losses involved."

In Texas the Houston Lighting and Power Company has asked the Department of the Army for a permit to build a nuclear plant in Upper Galveston and Trinity bays. This project poses a unique threat. The plant would take as much as 5,000 cubic feet per second of highly polluted water from the Houston ship channel and discharge it—hot and as polluted as ever—into the relatively clean waters of Trinity Bay.

Philip Douglas, executive secretary of the Sport Fishing Institute, states the case mildly when he says, "Adverse effects could be manyfold."

So it goes. Unless the conservation voices of the country are heeded, many of our rivers, lakes, and estuaries will be in hot water because of hot water in the next few years.

"We do not feel that thermal pollution is something we must live with, any more than we feel that some waters must be designated as sewers," protests the Sport Fishing Institute.

Secretary of the Interior Stewart Udall puts his finger on today's situation in these eloquent words:

"Here is an opportunity for a dose of preventive medicine. We did not have this opportunity with other pollutants. We must not miss our chance on this one. We must halt thermal pollution before it occurs!"

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STATEMENT OF METROPOLITAN DADE COUNTY, FLA.

METROPOLITAN DADE COUNTY, FLA.,
DADE COUNTY POLLUTION CONTROL,
Miami, Fla., October 15, 1968.

Senator EDMUND S. MUSKIE,
Chairman, Subcommittee on Air and Water Pollution,
Committee on Public Works,
U.S. Senate, Washington, D.C.

DEAR SENATOR MUSKIE: In reference to your letter of October 1, 1968, in which you request a description of the activities of our agency in reference to the Turkey Point facility of Florida Power and Light, since my testimony before the subcommittee I wish to submit the following.

With the cooperation of the Southeastern Regional Laboratory of the Federal Water Pollution Control Administration, the Dade County Pollution Control Department assisted in the servicing of temperature monitors throughout South Biscayne Bay to determine the background temperatures which could be expected during the summer months.

In the course of this study, it was found that temperatures in excess of those allowed within the Pollution Control Code were being found in the Bay in the vicinity of the present Turkey Point operations. For this reason, I issued a Notice of Violation to Florida Power and Light on August 29, 1968. On September 27, 1968, the power company submitted to me a reply which I considered inadequate as an application for variance. As an outgrowth of this, on September 30 I issued an order to the Building and Zoning Department of Dade County to remove all building permits previously issued for Florida Power and Light on their Turkey Point facility.

To date, no new applications have been submitted for the variance by Florida Power and Light. However, I have been informed that such applications will be shortly forthcoming.

I hope that this outlines to you what actions have been taken on the local front, and I appreciate all of the support we have been receiving from your subcommittee.

My best wishes for a successful campaign.

Respectfully yours,

PAUL WILLIAM LEACH,
Pollution Control Officer.

INFORMATION SUPPLIED BY THE NATIONAL WILDLIFE FEDERATION

NATIONAL WILDLIFE FEDERATION,
Washington, D.C., April 17, 1968.

Hon. EDMUND S. MUSKIE,
Senator From Maine,
New Senate Office Building,
Washington, D.C.

DEAR SENATOR ED: It was good to chat with you once again at our Houston meeting and to listen to another one of your fine speeches.

I am sending along under separate cover a copy of an agreement between the State of California and the Pacific Gas and Electric Company—the State of California acting through its resource agency. This agreement and the accompanying report on the marine fauna and flora of Diablo Cove, California, constitutes what appears to me to be a good working relationship between atomic power and local interests. Knowing of your sub-committee activities in this area, I thought perhaps this material might be of some interest to you and your research staff. It seems to me that this is the type of thing that we need a great deal more of—particularly in the East—if we are going to have intelligent planning prior to the establishment of atomic power installations.

Tom Riley, Executive Representative of PG & E Company, appears to be a most knowledgeable individual and sincerely interested in helping to solve the many conservation problems posed by atomic power.

Keep up the great work you are doing in conservation. If at any time I can be of any help to you or your staff in any way, please feel free to call on me.

Sincerely,

CARLL N. FENDERSON,
Northeastern Field Representative.

[Enclosures]

AGREEMENT

This Agreement, entered into in the City of Sacramento, State of California, this 6th day of December, 1966, between the State of California acting through its Resources Agency, and Pacific Gas and Electric Company (hereinafter called Pacific).

WITNESSETH:

Whereas, Pacific proposes to construct and operate a thermal electric generating station at a coastal site near Diablo Canyon in Rancho Canada de Los Osos y Pecho y Islay in San Luis Obispo County; and

Whereas, Pacific plans to construct a compacted fill across Diablo Creek to provide level areas for plant switchyard facilities; and

Whereas, Pacific plans to utilize sea water from the Pacific Ocean as condenser cooling water; and

Whereas, Pacific recognizes its responsibility to the general public to assist in the protection of the natural resources of the State of California; and

Whereas, the Resources Agency in its statement of policy dated June 30, 1965, has defined its objectives and principles regarding the location and operation of power plants,

Now, therefore, it is mutually agreed as follows:

1. The Resources Agency agrees that with respect to matters covered by this agreement or by Resources Agency's said statement of policy, it will not oppose Pacific in its applications for a certificate of public convenience and necessity for said plant, in proceedings before the Public Utilities Commission

of the State of California, or other pre-operational permits or operating licenses required by the Atomic Energy Commission or any other body having jurisdiction, and will indicate thereto that all matters covered by this agreement have been resolved to the satisfaction of the Resources Agency.

2. Pacific agrees that it will not deposit any surplus material excavated from the plant site in the Pacific Ocean or its tidelands, or in any bays, rivers, streams or inlets in the State of California, without first obtaining written authorization from the Resources Agency.

3. Pacific agrees that any fill to be constructed across Diablo Creek about 4,000 feet east of the mouth of Diablo Creek will be provided with adequate bypass facilities to pass flood waters of said creek and will be placed, graded, compacted, and provided with surface drainage facilities so as to minimize erosion of said fill.

Pacific further agrees to make any required application to the Central Coastal Regional Water Quality Control Board for construction of said fill.

4. Pacific agrees that any spoil material deposited on the land will be placed, graded, and compacted so as to minimize any transfer by erosion of the material to the beaches and ocean waters.

5. Pacific agrees that vehicular access, retaining walls, fences, buildings, and equipment will be located and designed in such a way that the physical appearance of the entire installation will be aesthetically compatible with the surroundings.

6. Pacific agrees that this agreement does not constitute approval of the State Lands Commission, the Central Coastal Regional Water Quality Control Board, or the State Water Quality Control Board if its jurisdiction is invoked, with respect to construction or operation or other activities of Pacific at the plant site, and Pacific further agrees that it will make appropriate applications to those agencies whenever reviews or approvals from such agencies are required for any activities in connection with the said plant. The Resources Agency agrees that it will not oppose Pacific in its seeking of required pre-operational reviews or approvals from such agencies with respect to matters covered by this agreement, and will indicate thereto that all matters covered by this agreement have been resolved to the satisfaction of the Resources Agency.

7. Pacific agrees to conduct or support investigations as outlined in the attachment titled "Ocean background investigation for proposed power plant site near Diablo Canyon, San Luis Obispo County, Pacific Gas and Electric Company", and to establish mutually acceptable design criteria for the protection of aquatic life in the waters which may be affected by the proposed facility or its operation. Resources Agency agrees to participate in these investigations and assist in the coordination with other agencies on studies which may yield desirable information.

The ecological study outlined under paragraph 7 "Specifications for Study" of the above-mentioned attachment will be conducted by Department of Fish and Game at Pacific's expense. Department of Fish and Game may conduct said study using its own personnel or by subcontracting with other groups.

Resources Agency and Pacific will jointly evaluate the data and from time to time during the course of the investigation may agree upon modifications of the investigation to achieve the objectives set forth in the attachment.

In the event critical problems relating to aquatic life or recreational uses occur after and as a result of plant installation, Pacific agrees to continue its cooperative investigations with the objective of modifying plant operation or design to eliminate these problems. In the event that adverse effects accrue to aquatic life or recreation uses due to plant construction or operation, Pacific will provide reasonable mitigation for losses incurred, provided such mitigation will not interfere with the construction or operation of the plant unless otherwise agreed.

8. Pacific agrees to conduct such water quality and radiological surveillance programs, both pre-operational and post-operational for the life of the plant, as may be developed in accordance with statutory authority of the State and Regional Water Quality Control Boards and the State Department of Public Health.

9. Pacific agrees to conduct a comprehensive geologic survey to determine the geologic conditions of the site—with particular reference to the nature of the foundation materials and seismic activity.

10. Pacific agrees that it will continuously evaluate the additional geologic information that is revealed during preparation of the site for construction, and take the appropriate steps in design and construction of the plant recognizing the geologic conditions.

11. Pacific agrees to furnish the Resources Agency with copies of all geologic reports pertaining to the site filed with other governmental agencies.

12. A copy of this agreement will be filed with the California Public Utilities Commission for its information.

In Witness Whereof, the parties have executed this agreement the day and year first hereinabove written.

STATE OF CALIFORNIA,
By HUGO FISHER,
Administrator, Resources Agency (On Behalf of the Department of Conservation, Department of Water Resources, Department of Parks and Recreation, Department of Fish and Game, Department of Harbors and Water Craft).

PACIFIC GAS & ELECTRIC CO.,
By JOHN F. BONNER,
Senior Vice President.

OCEAN BACKGROUND INVESTIGATION FOR PROPOSED POWER PLANT SITE NEAR DIABLO CANYON, SAN LUIS OBISPO COUNTY, PACIFIC GAS & ELECTRIC CO.

OBJECTIVES

The general objective of the investigation consistent with requirements of Central Coastal Water Quality Control Board is to develop information and data that will permit a quantitative description of environmental conditions prior to plant construction and operation and assist in the resolution of the effect of future plant discharges on the various beneficial uses of ocean waters near the plant site. This general objective includes the following specific objectives:

1. To develop qualitative and quantitative biological descriptions of the biotic community near the plant site, with due regard to seasons, tidal action and other temporal changes in order to provide background data prior to the construction and operation of discharge facilities.

2. To make a hydrographic study of temperature, salinity structure, and other physical factors that may influence the dilution and dispersion and reconcentration of waste discharge.

3. To evaluate, insofar as practical, simple indices or parameters that can be used for continuing surveillance after the plant is operating in order to determine quantitatively the effect of such discharges upon beneficial uses of ocean waters.

SPECIFICATIONS FOR STUDIES

The pre-operational study will be carried on commencing as far in advance as practicable of Pacific's application to the California Public Utilities Commission for a Certificate of Public Convenience and Necessity. Based on the results of the pre-operational study, a continuous program of monitoring during the operation of the plant will be established. The pre-operational study will include the following specific items:

1. A contour map showing bottom topography will be prepared of the area within one quarter mile of the plant.

2. Tide will be recorded locally over a long enough period of time to establish, if possible, a correlation with published tidal data.

3. Water surface temperatures in the area surrounding the plant site will be taken by near-instantaneous methods during a series of runs covering a tidal cycle. Data will be plotted for each run to define the existing thermal surface. These measurements will be repeated often enough to establish seasonal and other variations.

4. Vertical temperature and salinity profiles will be taken simultaneously with the measurements of surface temperature at not less than six stations offshore from the plant site.

5. Continuous water temperature records will be taken at not less than two stations during the pre-operational investigation. Data obtained will be correlated, if possible, with long-time temperature records obtained in the area by others.

6. Currents will be measured at at least six stations in the ocean waters during several tidal cycles and correlated, if possible, with tides. Measurements will be repeated often enough to establish seasonal and other variations. Additional studies will be made utilizing dyes to study dispersion and dilution.

7. An ecological study will be conducted having as its objective the establishment of a base inventory of the marine biota present from which the effect of the plant on the marine biota will be determined. All biota will be inventoried in order to establish that any ecological changes due to the plant operation are distinct from natural cyclic changes.

The study will require three field trips per year over a two-year period. Each trip will be conducted by a field party of three men covering a period of nine days. Total field work required covers approximately 81 man days per year. Laboratory work, evaluation and write-up requires 90 man days per year. Total time required is equivalent to eight man months per year.

The study will be conducted during the two-year period immediately prior to plant operation. The data obtained in the ecological study may be published by the Department of Fish and Game.

Post-operation studies will be determined following review of pre-operational study results and a program for further studies will be determined and mutually agreed upon. The post-operational study program will be reviewed periodically and revised to satisfy the parties hereto.

REPORTS

Quarterly reports of results without detailed data will be prepared. An annual report will be prepared which contains all observation in tabular or graphic form plus description. In addition, methods of observing, reducing data and analysis and laboratory tests will be described. Results will be presented in text and summarized in conclusions.

Agreement

This Agreement entered into in the City of Sacramento, State of California, this 6th day of December, 1966, between the State of California, acting through its Resources Agency (hereinafter called Resources Agency), and Pacific Gas and Electric Company, a California corporation (hereinafter called Pacific),

Witnesseth:

Whereas, Pacific has acquired certain lands in the Counties of Solano and Sacramento near Collinsville, California, for the purpose of constructing thereon, operating, and from time to time enlarging or reconstructing a thermal electric generating station herein called the Montezuma Power Plant, and

Whereas, Pacific plans to use water from the Sacramento-San Joaquin Delta as condenser cooling water in the Montezuma Power Plant, and

Whereas, the Resources Agency in its statement of policy dated June 30, 1965, has defined its objectives and principles regarding the location and operation of power plants, and

Whereas, Pacific recognizes its responsibility to the general public to assist in the protection of natural resources,

Now, therefore, it is mutually agreed as follows:

1. The Resources Agency agrees that with respect to matters covered by this agreement or by Resources Agency's said statement of Policy it will not oppose Pacific in its applications for a certificate of public convenience and necessity for said plant, in proceedings before the Public Utilities Commission of the State of California, or other pre-operational permits or operating licenses required by the Atomic Energy Commission or any other body having jurisdiction, and will indicate thereto that all matters covered by this agreement have been resolved to the satisfaction of the Resources Agency.

2. Pacific agrees that it will dispose of all spoil material on the plant site or otherwise and that it will not deposit any such spoil material in any bays, rivers, streams, or inlets in the State of California without first obtaining written authorization from the Resources Agency. Pacific agrees that it will use all reasonable precautions to avoid the introduction directly or indirectly of mud or silt or other debris into the waters of the Sacramento-San Joaquin Delta.

3. Pacific agrees that it will consult with flood control agencies having jurisdiction and take all reasonable precautions during its construction to prevent any impairment of flood control works, and it will reconstruct any impaired flood control works to a condition equal to or better than exists at the time of construction. Pacific will obtain all necessary permits or licenses from the agency having jurisdiction.

4. Pacific agrees that railroad access, vehicle access, retaining walls, fences, buildings, and equipment will be located and designed in such a way that the physical appearance of the entire installation will be esthetically compatible with the surroundings.

5. Pacific agrees that multi-purpose use of the plant site and construction features by the public shall be made wherever feasible consistent with public health and safety and the security and operation of the plant. Pacific agrees to present to the Resources Agency plans for public recreational uses of certain areas of the plant site that can properly be used for that purpose, and in cooperation with the Resources Agency to determine final plans and the manner of development of the site for recreational uses. The recreational uses to be contemplated by the plan may be developed by public agencies or Pacific or its licensees, permitees, or tenants, and may be subject to use charges consistent with charges made for similar developments in the general area. The Resources Agency recognizes that Pacific will retain the right to exclude the public in case of emergency from such portions of its land as are open to public recreational use.

6. Pacific agrees that roads constructed by it for the purposes of its power plant will be constructed to sufficient standards to permit safe public use thereon and will be open to public use for access to recreational facilities developed on the plant site subject only to such restrictions as may be necessary for the security and operation of the plant and the health and safety of the public. In the event that public agencies desire to construct additional roads over the plant site for access to recreational developments thereon, Pacific agrees to negotiate in good faith with the public agencies regarding Pacific's consent to the location of such roads and the terms and conditions of any such consent.

7. Pacific agrees to conduct such investigations as may be necessary to establish mutually acceptable design and operating criteria for the protection of aquatic life and recreational uses in the waters which may be affected by the proposed facility or its operation.

Resources Agency agrees to participate in these investigations and assist in the coordination with other agencies on studies which may yield desirable information. The objectives and specifications of these investigations are as outlined in the attachment titled: "Investigation into Sacramento-San Joaquin Delta Waters for Montezuma Power Plant Site, Pacific Gas and Electric Company."

Resources Agency and Pacific will jointly evaluate the data and from time to time during the course of the investigation may agree upon modifications of the investigation to achieve the objectives set forth in the attachment. Matters pertaining to water quality will be coordinated by the appropriate Water Quality Control Board.

In the event critical problems relating to aquatic life or recreational uses occur after and as a result of plant installation, Pacific agrees to continue its cooperative investigations with the objective of modifying plant operation or design to eliminate these problems.

8. Pacific agrees to conduct such water quality and radiological surveillance programs, both pre-operational and post-operational for the life of the plant, as may be developed in accordance with statutory authority of the State and Regional Water Quality Control Boards and the State Department of Public Health.

9. Pacific agrees to conduct a comprehensive geologic survey to determine the geologic conditions of the site—with particular reference to the nature of the foundation materials, possible subsidence, and seismic activity.

10. Pacific agrees that it will continuously evaluate the additional geologic information that is revealed during preparation of the site for construction, and take the appropriate steps in design and construction of the plant recognizing the geologic conditions.

11. Pacific agrees to furnish the Resources Agency with copies of all geologic reports pertaining to the site filed with other governmental agencies.

12. This agreement does not constitute approval of the State Lands Commission, the Regional Water Quality Control Board having jurisdiction over the waters affected, the State Water Quality Control Board if its jurisdiction is invoked, the State Water Rights Board, or the State Reclamation Board, with respect to construction, operation or other activities of Pacific at the Montezuma Power Plant Site, and Pacific further agrees that it will make appropriate applications to those agencies whenever approvals from such agencies are required for any activities in connection with the power plant. The Resources Agency,

however, agrees that it will not oppose Pacific in its seeking of pre-operational required approvals from such agencies with respect to matters covered by this agreement, and will indicate thereto that all matters covered by this agreement have been resolved to the satisfaction of the Resources Agency.

13. A copy of this agreement will be filed with the Public Utilities Commission of the State of California for its information.

In Witness Whereof, the parties have executed this agreement the day and year first hereinabove written.

STATE OF CALIFORNIA,
By HUGO FISHER,
Administrator, Resources Agency (On Behalf of the Department of Conservation, Department of Water Resources, Department of Parks and Recreation, Department of Fish and Game, Department of Harbors and Water Craft).

PACIFIC GAS & ELECTRIC CO.,
By JOHN F. BONNER,
Senior Vice President.

INVESTIGATION INTO DELTA WATERS FOR MONTEZUMA POWER PLANT SITE, PACIFIC GAS & ELECTRIC CO.

OBJECTIVES

The general objective of the investigation is to develop information and data that will permit a quantitative description of environmental conditions prior to plant construction and operation and assist in the resolution of the effect of future plant discharges on the various beneficial uses of delta waters near the plant site. This general objective includes the following specific objectives:

1. To develop qualitative biological, physical and hydrographic descriptions of the overlying waters, bottom and shore conditions of the waters near the plant site, with due regard to seasons, tidal action and other temporal changes in order to provide background data prior to the construction and operation of discharge facilities.
2. To study temperature, salinity structure, and other factors that may influence the dilution and dispersion and reconcentration of waste discharge.
3. To evaluate, insofar as practical, indices or parameters that can be used for continuing surveillance after the plant is operating in order to determine quantitatively the effect of such discharges upon beneficial uses of the delta waters.
4. To correlate and integrate such investigations with the research program being sponsored by the State Water Quality Control Board, the Department of Water Resources, and others.

SPECIFICATIONS FOR STUDIES

The pre-operational study will be carried on commencing as far in advance as practicable of Pacific's application to the CPUC for a Certificate of Public Convenience and Necessity. It is anticipated that all unresolved questions between the Resources Agency and Pacific will be settled, and the final report will be completed prior to the CPUC public hearing. Based on the results of the pre-operational study, a continuous program of monitoring during operation of the plant will be established. The pre-operational study will include the following specific items:

1. A contour map showing bottom topography will be prepared of the area within 1000 ft. of shore extending from the town of Collinsville to a point 2000 ft. east of Marshall Cut.
2. Tide will be recorded locally over a long enough period of time to establish, if possible, a correlation with published tidal data.
3. Surface water temperatures in the area surrounding the plant site will be taken by near-instantaneous methods during a series of runs covering a tidal cycle. Data will be plotted for each run to delineate the existing thermal surface. These measurements will be repeated often enough to establish seasonal and other variations.
4. Vertical temperature and salinity profiles will be taken simultaneously with the measurements of surface temperature at not less than six stations offshore from the plant site.
5. Continuous water temperature records will be taken at not less than two stations during the pre-operational investigation. Data obtained will be cor-

related, if possible, with long-time temperature records obtained in the area by the Department of Water Resources and others.

6. Currents will be measured at at least six stations in the waters around Montezuma Island during several tidal cycles. Measured currents will be correlated, if possible, to tides. Measurements will be repeated often enough to establish seasonal and other variations.

In addition to the above specific physical measurements, it is recognized that certain work in connection with aquatic life to determine acceptable plant design criteria may be necessary. Areas of possible concern are the effects on aquatic life of (a) the location and design of the intake and outlet structure, (b) the purpose and design of the intake screening device, and (c) the change in temperature due to heat exchange.

Inasmuch as there are many current investigations into delta biological problems, it is impossible to anticipate at this time what new knowledge will be available at the time Pacific is ready to proceed with the development of the site. Accordingly, it is understood and agreed that when Pacific decides to proceed with the Montezuma plant, the Resources Agency and Pacific will examine the current state of knowledge and will at that time agree on a mutually satisfactory investigation to resolve the significant uncertainties with respect to the relationship of the plant to aquatic life.

REPORTS

Quarterly reports giving summaries of results will be prepared. An annual report will be prepared which contains all observations in tabular or graphic form plus description. In addition, methods of observing, reducing data and analysis and laboratory tests will be described. Results will be presented in text and summarized in conclusions.

An Evaluation of the Marine Fauna and Flora in the Vicinity of Diablo Cove, Calif.

(By Wheeler J. North)

OBJECTIVES

During preliminary planning of the survey there was little information available concerning the biota of the coastline between Morro Bay and Point San Luis. The first objective, accordingly, was to gather sufficient general information from *in situ* inspections so that an adequate survey could be designed. Immediately before the first visit, a report by Earl E. Ebert,[1] Department of Fish and Game, State of California, became available and supplied a substantial part of the general information needed. On the basis of this knowledge plus information gathered during our survey, it is believed that an adequate study was conducted and the first objective satisfactorily achieved. Other objectives were:

2. Describe the physical environment in terms useful for ecological assessments.
3. Identify the principal animal and plant species.
4. On the basis of items 2 and 3, develop a general ecological description of the study area.
5. Without excessive speculation, furnish reasonable predictions of effects that a warm discharge may have on the biota.
6. Suggest precautions that might aid in conserving the biota.

Concerning items 2 and 3, one can measure parameters and collect specimens virtually *ad infinitum* and continue to develop useful information. Nonetheless a point of diminishing returns is reached and it is believed that this position has been attained when information from the present survey is combined with results from prior studies. The current state of knowledge is sufficient to permit significant progress in achieving objectives 4, 5, and 6.

An additional objective should be mentioned but was not undertaken because of time limitations. Seasonal changes in the biota and the physical environment should be determined. Appropriate times for such work would be mid-to-late

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[1] Ebert, E. E., 1966, an evaluation of marine resources, Pt. Buchon to Pt. San Luis, San Luis Obispo County, with particular reference to abalone and the Diablo Canyon area May 2–4, 1966, Department of Fish and Game, State of California.

spring near the end of the stormy season, and again in mid-August to early September, when sea surface temperatures are likely to be maximal.

No emphasis was placed on commercially important species such as fish and abalone in the present study. These have already been given considerable attention in the reports by Ebert and by Frances Clark. Likewise the general character of the present study developed information that applies both to commercially important as well as to other species. If seasonal studies are undertaken, however, somewhat more emphasis should be given to the commercial species.

THE PHYSICAL ENVIRONMENT

Diablo Cove is a major indentation in an exposed and extremely rugged rocky coast. The highly irregular terrestrial topography is also representative of the sea floor. Smooth areas are limited and dimensions of the irregularities range from ridges measuring fractions of an inch to pinnacles standing 10 to 40 feet high. Sand and small cobbles fill some of the depressions, but the sediment cover on the bottom is not extensive.

Underwater visibility was good at the time of our visits, contrasting to the rather fair conditions found by Ebert's group in late spring. Bottom light intensities were low, but measurements were made on an overcast day (Table 1). On a clear day intensities would probably have been 50 to 100 times greater and submarine illumination values would be classed as excellent. Dense algal growths extended to depths of 50 to 60 feet, indicating that the light climate of the region was indeed good. The algal cover might extend even deeper if grazing urchins were removed.

Temperature was uniform from the surface to the deepest point reached (80 feet). Values of about 14° C were obtained, which is approximately normal for the area at the time of the study. The fauna and flora were a mixture of warm-water and cold-water forms. The warm-water species, however, were organisms that survive cold temperatures without apparent ill effects, but there were many cold-water species that do poorly in warmer temperatures. It was assumed, therefore, that water temperatures are characteristically cold in the region and that the presence of warm-water species was due to the proximity of their centers of distribution, south and east of Point Conception.

TABLE 1.—BOTTOM AND TOPSIDE LIGHT INTENSITIES

[Light intensities are given in ergs/cm.²/sec at Diablo Cove on Nov. 5, 1966. Measurements were made while swimming along transects D and F (fig. 1). Cloud cover changed substantially during the period so that surface illumination varied. The sky was overcast throughout and intensities about 50 to 100 times greater would be expected on a clear day.]

Time	Depth (feet)	Intensity, ergs/cm.²/sec					
		Red [1]	Orange [1]	Yellow [1]	Green [1]	Blue [1]	Violet [1]
09:50	0	9,400	5,700	10,000	15,000	8,800	8,900
10:00	70	66	130	350	720	370	150
	60	170	370	960	1,800	940	430
10:25	50	370	460	2,100	2,300	2,000	2,300
11:15	10	5,000	5,500	13,000	17,000	11,000	11,000
	20	2,500	3,100	6,200	9,300	4,900	3,000
	30	1,800	2,400	5,500	9,300	4,900	3,000
12:00	40	870	1,500	4,100	6,500	2,600	1,400
12:30	0	48,000	23,000	45,000	66,000	25,000	30,000

[1] Characteristics of the color filters and a description of the light meter are given in Anderson and North, Annual Report, Kelp Habitat Improvement Project, 1965–66, California Institute of Technology pp. 31 to 44.

Many species characteristic of cold water were found in the intertidal zone. A substantial number were attached forms such as plants, requiring months or longer to develop. Their presence at this level suggests that fairly cold water exists throughout the water column even in summer. Thermoclines are probably reduced or absent throughout the year.

Wave exposure is greatest from the southwest. Some protection to swells from the west and northwest is offered by Diablo Rock and a shallow sill (Figure 1). Virtually complete protection is provided by the mainland in all other directions. in spite of the protection, longer or foliose algae are restricted primarily to deeper levels, suggesting that wave action is severe.

Although the surrounding headlands and offshore islands offer considerable lee from swells, Diablo Cove is very elongate across the entrance and is not sufficiently indented to form a baylike environment. All organisms found were typical of exposed rocky coasts. Water circulation and mixing are probably very well developed in all parts of the Cove.

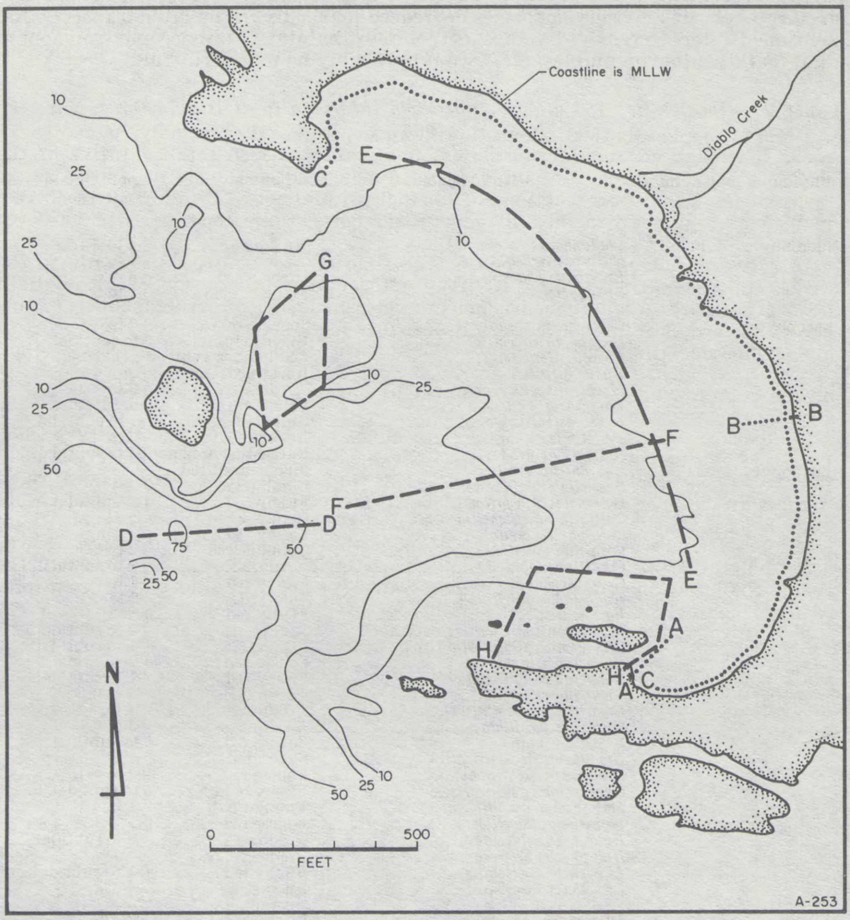

FIGURE 1. Diablo Cove, showing position of transects studied in November, 1966. Alphabetical designation of subtidal transects indicates order in which they were surveyed. Depths are in feet.

PLANT AND ANIMAL SPECIES

All species observed along three intertidal and five subtidal transects (Figure 1) were identified to the lowest taxon possible without seeking assistance from specialists. Intertidally, 44 plant species and 64 animal species were recorded (Tables 2 and 3). Subtidally, 52 plant forms and 134 animal types were identified (Tables 4 and 5). As indicated above, the biota was a mixture of northern and southern forms and those species that are common in warm water in southern California have been designated by an asterisk in the tables. Many forms could be identified only to families or genera. Such categories were counted as a single species in arriving at the totals cited above. Actually these groups may contain two or more species, hence the totals are minimal values. Undoubtedly species were overlooked or not recognized while running the transects. Crevice environments in particular were incompletely surveyed, simply due to lack of time. New species may appear in other seasons. Ebert's report lists 22 species not observed in the present survey.

Probably the list of plant species is fairly complete (Ebert recorded only one alga not listed by us) but the total complement of animals in Diablo Cove may easily be double the number in our list. It is believed that additional transects in other parts of the Cove would probably not yield large numbers of additional species since recovery of unobserved species decreased markedly in the later transects. As mentioned, more intensive studies of complex habitats (crevice environments, algal mats, sediment samples, etc.) would probably be more fruitful.

TABLE 2.—*Species list of seaweeds observed intertidally at Diablo Cove, Nov. 12, 1966*

Phylum or major group	Scientific name	Common name	Approximate level or range, feet
Chlorophyta	*Cladophora trichotoma* [1]	Sea grass	+4 to +1.
	Codium Setchelli		+1 to −1.
	Enteromorpha sp.[1]	Green weed	+3 to 0.
	Spongomorpha coalita	Filamentous green.	+1 to 0.
Phaeophyta	*Colpomenia sinuosa* [1]	Spongy kelp	+2 to 0.
	Dictyoneurum californicum	Blade kelp	0 to subtidal.
	Egregia Menziesii [1]	Feather boa kelp	Do.
	Fucus furcatus	Rockweed	+3 to +1.
	Hesperophycus Harveyanus [1]	do	+3 to +2.
	Laminaria Andersonii	Palm kelp	0 to subtidal.
	Nereocystis leutkeana	Bull kelp	−1 to subtidal.
	Pelvetia fastigata [1]	Rockweed	+3 to +2.
	Ralfsia pacifica [1]	Encrusting brown	+3 to subtidal.
Rhodophyta	*Agardhiella Coulteri* [1]	Filamentous red	0.
	Bossiella orbigniana [1]	Coralline red	0 to 1.
	Botryoglossum farlowianum	Fleshy red	0 to subtidal.
	Calliarthron Setchelliae [1]	Coralline red	Do.
	Callophyllis crenulata	Fleshy red	Do.
	Corallina gracilis [1]	Coralline red	+2 to 0.
	Corallina chilensis [1]	do	+1 to subtidal.
	Cryptosiphonia Woodii	Fleshy red	+1 to 0.
	Endocladia muricata [1]	Busy red	+2 to +1.
	Farlowia sp	Fleshy red	0.
	Gastroclonium Coulteri	do	+2 to subtidal.
	Gelidium cartilagineum [1]	do	+1 to subtidal.
	Gigartina Binghamiae [1]	Foliose red	0 to subtidal.
	Gigartina canaliculata [1]	Fleshy red	+1 to subtidal.
	Gigartina cristata	do	+2 to 0.
	Gigartina leptorhyncus [1]	do	+1 to −1.
	Gigartina papillata	do	+3 to 0.
	Gigartina volans [1]	Foliose red	0 to subtidal.
	Gracilariopsis Sjoestedtii [1]	Fleshy red	0
	Grateloupia schizophylla	Foliose red	+2 to −1.
	Gymnogongrus linearis	Fleshy red	0 to subtidal.
	Halosaccion glandiforme	Tubular red	+1 to −1.
	Hymenena flabelligera	Foliose red	0.
	Iridophycus flaccidum	do	+2 to subtidal.
	Iridophycus heterocarpum	do	Do.
	Laurencia spectabilis	Fleshy red	+1 to subtidal.
	Lithothamnium sp.[1]	Encrusting coralline.	Do.
	Plocamium pacificum [1]	Fleshy red	Do.
	Polysiphonia californica	Filamentous red	0 to subtidal.
	Porphyra perforata	Foliose red	+4 to +1.
	Prionitis linearis [1]	Stringy red	+1 to subtidal.
	Rhodoglossum affine [1]	Bushy red	+2 to 0.
	Rhodomela floccosa	Fleshy red	0.
	Smithora niaidum [1]	Epiphytic red	0 to subtidal.
Spermatophyta	*Phyllospadix Scouleri* [1]	Surf grass	+2 to subtidal.

[1] Occurs in warm water.

TABLE 3.—*Species list of animals observed intertidally at Diablo Cove, Nov. 12, 1966*

Phylum or major group	Scientific name	Common name	Approximate level or range, feet
Protozoa	*Gromia oviformis* [1]	Foraminiferan	+1 to subtidal.
Porifera	*Cliona* sp	Sponge	0.
	Haliclona spp	do	0 to subtidal.
Coelenterata	*Anthopleura elegantissima* [1]	Anemone	+2 to −1.
	Anthopleurax anthogrammica [1]	do	0 to subtidal.
	Sagartia elegans [1]	do	Do.
Platyhelminthes	*Leptoplana chloranta* [1]	Flatworm	+1 to −1.
Bryozoa	*Hippothoa hyalina*	Moss animal	0 to subtidal.
	Lyrula hippocrepis	do	−1
	Membranipora membranacea [1]	do	On drift kelp.
	Membranipora villosa	do	0.
	Microporella sp. or spp	do	+1 to subtidal.
	Rhyncozoon rostratum	do	0 to subtidal.
Annelida:			
Polycheta	*Dexiospira spirillum* [1]	Spiral worm	Do.
	Eupomatus	Tube worm	0.
	Nereidae [1]	Worm	+1 to subtidal.
	Sabellariidae [1]	Tube worm	0 to subtidal.
	Spionidae	Worm	+ 1 to subtidal.
	Terebellidae [1]	do	0 to subtidal.
Mollusca:			
Amphineura	*Mopalia muscoso* [1] (unidentified chiton	Hairy chiton	+1 to −1.
Gastropoda	*Acanthina spirata*	Unicorn snail	+2 to 0.
	Aclis sp	Snail	+1.
	Acmaea pelta[1]	Limpet	+6 to 0.
	Acmaea persona[1]	do	+2.
	Acmaea scabra[1]	do	+3 to +2.
	Haliotis cracherodii[1]	Black abalone	+3 to subtidal.
	Haliotis rufescens	Red abalone	0 to subtidal.
	Lacuna porrecta	Chink snail	+1 to 1−1.
	Littorina planaxis[1]	Periwinkle	+7 to +4.
	Littorina scutulata[1]	do	+2 to +1.
	Lottia gigantea[1]	Giant limpet	+6 to +2.
	Mitrella aurantiaca	Dove snail	+2 to 0.
	Spiroglyphis lituellus	Tube snail	0.
	Tegula brunnea	Brown top snail	+1 to subtidal.
	Tegula funebralis[1]	Black top snail	+3 to 0.
Pelecypoda	*Chama pellucida*[1]	Rock clam	+1 to subtidal.
Arthropoda:			
Crustacea	*Balanus glandula*[1]	Barnacle	+3 to +1.
	Cancer sp	Rock crab	0.
	Chthamalus fissus[1]	Barnacle	+3 to +2.
	Cirolana harfordi[1]	Pillbug	+1 to subtidal.
	Hemigrapsus oregonensis[1]	Crab	0.
	Idothea sp	Isopod	0.
	Lygia occidentalis[1]	do	+6 to +3.
	Mimulus foliatus[1]	Decorater crab	+1 to −1.
	Pachycheles pubescens[1]	Rock crab	0.
	Pachycheles rudis[1]	do	0.
	Pagurus granosimanus[1]	Hermit crab	+1 to subtidal.
	Pagurus hirsutiusculus[1]	do	Do.
	Petrolisthes eriomerus[1]	Porcelain crab	Do.
	Pugettia richii	Kelp crab	+1.
	Pugettia productus[1]	do	+2 to subtidal.
	Tetraclita squamosa[1]	Barnacle	+1 to −1.
	Pachygrapsus crassipes[1]	Shore crab	+3 to 0.
Echinodermata:			
Asteroidea	*Linckia* sp	Sea star	+1.
	Pateria miniata [1]	Bat star	+1 to subtidal.
	Pisaster ochraceous [1]	Ochre star	Do.
	Pycnopodia helianthoides	Sun star	0 to subtidal.
Echinoidea	*Strongylocentrotus purpuratus* [1]	Purple urchin	+2 to subtidal.
Chordata:			
Urochordata	*Cystodites* sp	Sea squirt	+1 to subtidal.
	Pycnoclavella stanleyi	do	0.
Pisces	*Xererpes fucorum*	Rockweed blenny	+1 to −1.
Aves	*Larus* sp.[1]	Sea gull	
Mammalia	*Zalophus* [1]	Sea lion	

[1] Occurs in warm water.

TABLE 4.—*Species list of plants observed subtidally at Diablo Cove, Nov. 5 and 6, 1966*

Phylum or major group	Scientific name	Common name	Approximate depth or depth range, feet
Chlorophyta	*Byropsis corticulans*		30.
	Cladophora [1]	Sea grass	10.
	Ulva lobata	Sea lettuce	5 to 20.
Phaeophyta	*Cystoseira osmundacea* [1]	Kelp	30 to 40.
	Dictyoneurum californica	do	20 to 40.
	Dictyota binghamiae [1]		10.
	Desmarestia herbacea		10 to 30.
	D. munda		Do.
	Ectocarpus [1]	Filamentous brown.	30.
	Egregia Menziesii	Feather boa kelp	10.
	Laminaria Andersonii	Palm kelp	20 to 60.
	Nereocystis leutkeana	Bull kelp	10 to 50.
	Pterygophora californica	Palm kelp	20 to 70.
Rhodophyta	*Acrosorium uncinatum* [1]	Red algae	0 to 50.
	Aeodes gardneri	do	40.
	Amplisiphonia	do	
	Botryoglossum farlowianum	do	10 to 40.
	Bossiella corymbifera	do	20.
	Bosiella gardneri	do	20.
	Calliarthron cheilisporoides	do	10 to 70.
	Calliarthron regenerans	do	20.
	Callophyllis firma	do	10 to 20.
	Callophyllis flabellulata	do	30 to 60.
	Callophyllis violacea	do	30.
	Cryptosiphonia Woodii	do	30.
	Endocladia muricala [1]	do	10.
	Fryeela gardneri	do	60.
	Gastroclonium coulteri	do	10.
	Gelidium robustum [1]	do	10 to 30.
	Gigartina canaliculata [1]	do	10 to 40.
	Gigartina corymbifera [1]	do	10 to 30.
	Gigartina binghamiae [1]	do	10 to 50.
	Gigartina Leptorhynchus [1]	do	10.
	Gigartina papillata	do	5.
	Grateloupia schizophylla	do	5.
	Gymnogongrus platyphyllus	do	10.
	Hildenbrandia prototypus	do	
	Iridophycus flaccidum	do	10.
	Iridophycus heterocarpum	do	5.
	Laurencia spectabilis	do	20.
	Lithothamniom [1]	do	80.
	Opuntiella californica	do	30 to 60.
	Peyssonnelia pacifica	do	10 to 70.
	Polyneura latissima	do	30 to 60.
	Prionitis lanceolata	do	10.
	Prionitis linearis [1]	do	10 to 20.
	Pterosiphonia gracilis	do	20.
	Ptilota densa	do	30.
	Rhodoglossum affine [1]	do	5.
	Weeksia reticulata	do	30 to 60.
Chrysophyta	*Licmorpha* sp.[1]	Diatom	30.
Spermatophyta	*Pyllospadix scouleri* [1]	Surf grass	10 to 20.

[1] Occurs in warm water.

TABLE 5.—*Species list of animals observed subtidally at Diablo Cove, Nov. 5 and 6, 1966*

Phylum or major group	Scientific name	Common name	Approximate depth or depth range, feet
Protozoa	*Gromia oviformis* [1]	Foraminiferan	Intertidal to 20.
Porifera	*Acarnus erichthacus*	Sponge	
	Hymenamphiastra	do	30.
	Leuconia heathii	do	20 to 40.
	Leucosolenia eleanor	do	20 to 40.
	Rhabdodermella nuttingi	do	20 to 40.
	Spheciospongia confederata [1]	Liver sponge	15.
	Tethya aurantia	Puffball sponge	70.
	Tetilla arb	Sponge	20 to 40.
Coelenterata:			
Hydrozoa	*Abietinaria*	Ostrich plume	10 to 50.
	Aglaophenia [1]	do	20 to 30.
	Allopora	Blue coral	60 to 80.
	Campanularia	Hydroid	10 to 30.
	Halecium	do	
	Obelia [1]	do	
	Plumularia	do	
	Sertularella [1]	do	
	Sertularia [1]	do	
Scyphozoa	*Haliclystus*		20.
Anthozoa	*Anthopleura xanthogrammica* [1]	Anemone	
	A. elegantissima [1]	do	
	A. artemesia	do	
	Balanophyllia elegans	Cup coral	50 to 70.
	Corynactis	Pink anemone	40 to 70.
	Sagartia elegans [1]	Anemone	20 to 40.
	Telia	do	30 to 70.
Bryozoa	*Cauloramphus*	Moss animal	
	Costazia [1]	do	
	Crisia	do	
	Diaporoecia [1]	do	20 to 30.
	Diasporella	do	
	Flustrella	do	
	Holoporella	do	
	Hippothoa	do	
	Lagenipora	do	
	Lyrula	do	
	Membranipora fusca	do	
	Membranipora membranacea [1]	do	Encr. on kelp.
	Microporella	do	20.
	Mucronella	do	
	Parasmittina	do	
	Pherusella	do	
	Phidolopora [1]	do	30 to 50.
	Rhyncozoon	do	
	Scrupocellaria	do	
	Thalamoporella	do	50.
	Tricellaria	do	
	Tubulipora	do	
Nemertea	(Unidentified)	Ribbon worn	20.
Sipunculoidea	do	Peanut worm	20.
Annelida: Polycheta	*Chaetopterus* [1]	Fan worm	30 to 70.
	Dexiospira [1]	Spiral worm	10 to 50.
	Eudistyla [1]	Feather duster	20 to 70.
	Nereidea	Worm	10 to 30.
	Polynoidae	Scale worm	20 to 40.
	Salmacina tribranchiata	Tube worm	30.
	Serpula [1]	do	40.

[1] Occurs in warm water.

TABLE 5.—*Species list of animals observed subtidally at Diablo Cove, Nov. 5 and 6, 1966*—Continued

Phylum or major group	Scientific name	Common name	Approximate depth or depth range, feet
Mollusca:			
Amphineura	*Cryptochiton*	Gumboot	20 to 40.
	Chiton, unidentified		30.
	Ischnochiton mertensii		20.
	Ischnochiton radians		20.
Gastropoda	*Acmaea incessa* [1]	Limpet	5 to 20.
	Acmaea mitra	do	10 to 50.
	Acmaea paleacea [1]	do	20.
	Acmaea persona [1]	do	3 to 15.
	Aletes squamigerous [1]	Tube mollusk	40.
	Astraea inequalis	Top snail	20 to 60.
	Calliostoma annulata	Ringed top snail	10 to 70.
	Calliostoma costatum	Ribbed top snail	20 to 40.
	Crepidula [1]	Slipper shell	
	Fissurella [1]	Keyhole limpet	10.
	Haliotis chracherodii [1]	Black abalone	2 to 10.
	Haliotis rufescens	Red abalone	10 to 60.
	Hopkinsia rosacea [1]	Pink nudibranch	10.
	Jaton [1]	Snail	
	Margarites	do	
	Mitra ida	do	70 to 40.
	Mitrella aurantiaca	Dove shell	
	Nassarius [1]	Whelk	40.
	Norrisia [1]	Smooth turban	20.
	Pteropurpura [1]	3-wing murex	
	Tegula brunnea	Brown top snail	
	Tegula funebralis [1]	Black top snail	5.
	Tegula montereyi	Monterey top snail.	20 to 50.
	Tegula pulligo	Dusky top snail	
Pelecypoda	*Hinnites* [1]	Rock scallop	40 to 70.
	Mytilus californianus [1]	Mussel	2.
	Saxicava (Hiatella) sp	Clam	20 to 40.
Arthropoda:			
Crustacea	*Balanus crenatus*	White barnacle	5 to 50.
	Balanus nubilis	Giant barnacle	40.
	Balanus tintinnabulum [1]	Pink barnacle	70.
	Cancer sp	Crab	20.
	Caprella sp	Amphipod	10 to 50.
	Cirolana sp	Pillbug	
	Crago	Shrimp	30.
	Gammaridea	Amphipod	
	Idothea resecata	Kelp isopod	On kelp blade
	Loxorhyncus	Spider crab	20 to 40.
	Mimulus	Decroater crab	
	Pagurus sp	Hermit crab	
	Petrolisthes	Porcelain crab	20.
	Pugettia producta [1]	Kelp crab	20.
Pycnogonida	*Tanystalum occidentalis*	Sea spider	20.
Echinodermata:			
Asteroidea	*Astrometis sertulifera* [1]	Spiny star	30 to 40.
	Henricia levisculis	Spindle star	20 to 30.
	Pateria miniata	Bat star	20 to 70.
	Pisaster giganteus [1]	Giant star	50.
	Pisaster ochraceous [1]	Ochre star	5.
	Pycnopodia helianthoides	Sun star	30 to 40.
Echinoidea	*Strongylocentrotus franciscanus*	Giant urchin	15 to 80.
	Strongylocentrotus purpuratus [1]	Purple urchin	20 to 40.
Ophiuroidea	*Ophioncus granulosus*	Brittle star	30.
	Ophiothrix spiculata	do	20 to 60.
Holothuroidea	*Stichopus*	Sea cucumber	60.
Chordata			
Urochordata	*Ascidia ceratodes*	Sea squirt	20 to 40.
	Boltenia villosa	do	Do.
	Botryllus sp		
	Metandrocarpa sp		50.
	Sigillinaria sp		20 to 40.
Pisces	*Anisotremus davidsoni* [1]	Sargo	20 to 30.
	Clinocottus analis	Wooly sculpin	40.
	Embiotoca jacksoni [1]	Black perch	20 to 70.
	Girella nigricans [1]	Opaleye	10 to 30.
	Heterostichus [1]	Kelpfish	30 to 60.
	Leiocottus hirundo [1]	Lavender sculpin	20.
	Lepidogobius lepidus	Pale goby	20 to 40.
	Ophiodon elongatus	Ling cod	40 to 70.
	Oxyjulis californica [1]	Senorita	40.
	Paralabrax clathratus [1]	Kelp bass	10 to 70.
	Scorpaena guttata	Sculpin	30.
	Scorpaenicthys marmoratus	Cabezone	30.
	Sebastodes mystinus	Blue rockfish	10 to 70.
	Sebastodes sp. (various)	Rockfishes	10 to 50.
Mammalia	*Zalophus* [1]	Sea lion	0 to 40.

[1] Occurs in warm water.

Such intensive studies were not attempted for several reasons. One important purpose of recording organism varieties, namely to gain a concept of species diversity, was adequately fulfilled. It was clearly established that the biota comprises an extremely diversified assemblage of plants and animals. Another objective fulfilled by species lists is to establish beforehand conditions to assist in evaluating subsequent changes. If any serious changes occur in Diablo Cove, certainly a great many of the species we have recorded will be affected and it is believed that our lists provide a reasonably adequate basis for future assessments. Finally, species lists are a *sine qua non* for determining ecological relationships such as food chains, energy flows, community structure, succession patterns, etc. Unfortunately recording species for these purposes is a task almost without end since one can never be certain that some crucial but obscure organism has not been overlooked. For present requirements only rather general concepts of the ecology are needed and the usual approach to such an understanding involves consideration primarily of the large, obvious, dominant organisms. Almost certainly these are represented quite completely in our lists.

Our survey concentrated almost exclusively on Diablo Cove. Additional information on adjacent regions would be desirable. It was felt, however, that top priority should be assigned to the Cove and further work could be done in other locations after a sufficient understanding had been achieved for this, the most critical region. The reports by Ebert and by Clark treat adjacent areas to some extent so they are not completely unknown, and this confirmed our decision to concentrate our limited resources in studies of the Cove.

Quantitative measurements were made only along Transects A and B (Figures 2 and 3, Tables 6 and 7). These were undertaken more for the purpose of scrutinizing two randomly selected areas, rather than for developing meaningful absolute values for population concentrations, percent plant coverage, etc. It should be emphasized that the biota is so luxuriant and diversified that a large and sophisticated effort will be necessary to produce quantitative data sufficiently reliable to be of use. At the present time it would be difficult to judge how much work would be necessary, and it is not at all certain that the effort would be justified in terms of being able to evaluate changes with significantly increased precision. These difficult questions should be resolved somewhat by information on seasonal changes.

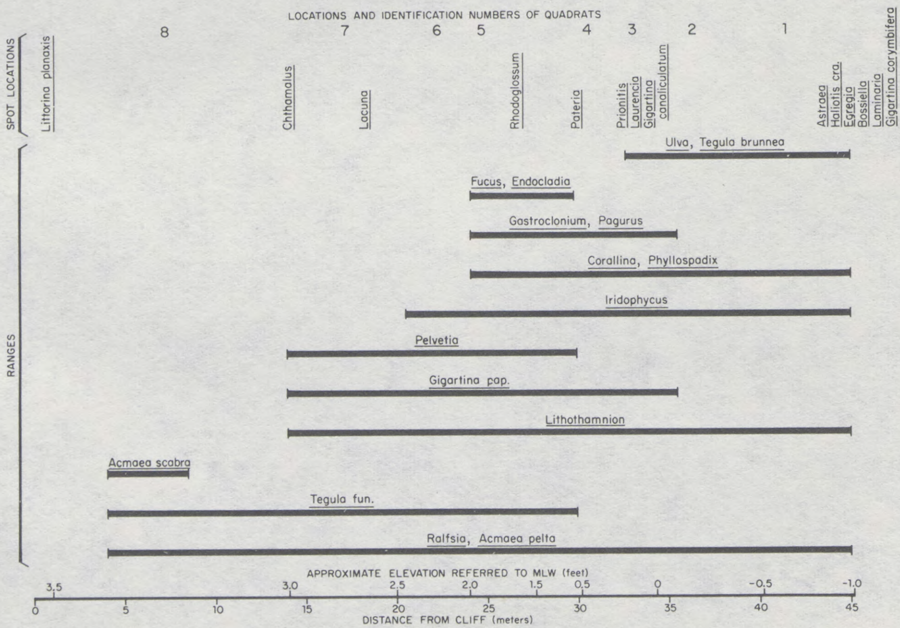

FIGURE 2. Ranges and/or locations of dominant organisms, Transect A, south side of Diablo Cove, 12 November 1966

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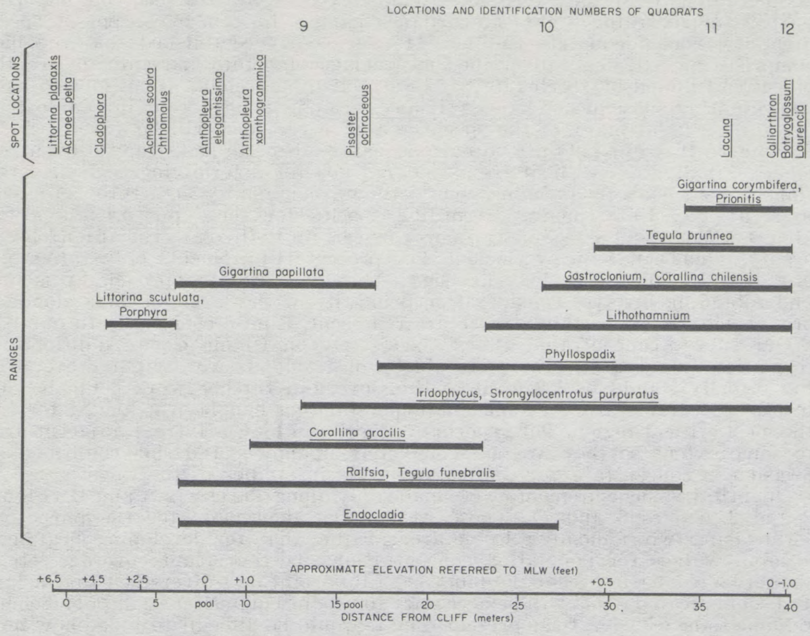

FIGURE 3. Ranges and/or locations of dominant organisms, Transect B, central Diablo Cove, approximate likely future location of discharge, 12 November 1966.

TABLE 6.—*Quadrat contents along transect A, Diablo Cove, Nov. 12, 1966. Quadrat was a brass square, 25 cm. on a side. Locations of quadrats shown on chart of the transect. Positions obtained by blind casts.*

Quadrat No.	Organisms per quadrat or percent cover	
	Animals	Plants
1	5 *Acmaea pelta* 7 *Tegula brunnea*	12 *Gigartina corymbifera* (Juv.). 25 percent *Lithothamnium*. 5 percent *Ralfsia*.
2	3 *Acmaea pelta* 1 Chiton, unidentified 6 *Pagurus* sp 8 *Tegula Brunnea*	8 *Gigartina papillata*. 15 percent *Gigartina canaliculatum*. 2 percent *Corallina*. 6 *Iridophycus*. 1 *Laurencia*. 2 *Ulva*.
3	3 *Acmaea pelta* 2 percent Bryozoa, unidentified	30 percent *Gigartina papillata*. 3 *Iridophycus* (ca. 30 percent coverage). 2 percent *Lithothamnium*. 5 percent *Ralfsia*. 2 percent *Ulva*.
4	5 *Tegula Brunnea* 15 *Tegula funebralis*	5 percent *Endocladia*. 2 *Gastroclonium*. 10 percent *Gigartina papillata*. 5 percent *Lithothamnium*. 1 percent *Ralfsia*. 5 percent *Rhodoglossum*. 5 percent *Ulva*.
5	1 *Pagurus* sp 140 *Tegula funebralis*	10 percent *Corallina*. 1 *Gastroclonium*. 20 percent *Gigartina papillata*. 4 *Iridophycus*. 5 percent *Lithothamnium*. 2 percent *Ralfsia*.
6	5 *Acmaea pelta* 1 Blenny, unidentified, many *Lacuna* (hidden in algae). 1 unidentified polychaete. 50 *Tegula funebralis*.	20 percent *Gigartina papillata*. 5 percent *Ralfsia*.
7	3 *Acmaea pelta* 7 *Tegula funebralis*.	3 percent *Lithothamnium*.
8		5 percent *Ralfsia*.

TABLE 7.—*Quadrat contents along transect B, Diablo Cove, Nov. 12, 1966. Quadrat was a brass square, 100 cm. on a side, divided into smaller squares 50 cm. on a side. Animals were enumerated within a ¼m² area and plants were enumerated within a 1m² area. Locations of quadrats shown on chart of the transect. Quadrat positions were the result of blind casts.*

Quadrat No.	Organisms per quadrat or percent cover	
	Animals (per ¼ m.²)	Plants (per m.²)
9	37 *Tegula funebralis* 2 *Strongyltocentrotus purpuratus*	25 percent *Endocladia*. 30 percent *Gigartina papillata*. 5 percent *Iridophycus*. 40 percent *Ralfsia*.
10		10 percent *Corallina chilensis*. 5 percent *Endocladia*. 50 percent *Gastroclonium*. 30 percent *Iridophycus*. 5 percent *Ralfsai*.
11	1 *Cancer sp* 1 *Fissurella* 1 *Henricia* 2 *Mitrella* 1 *Pugettia* 1 *Tegula brunnea*	90 percent *Gastroclonium*. 12 *Iridophycus*. 1 percent *Lithothamnium*. 1 percent *Laurencia*. 1 percent *Phyllospadix*. 5 percent *Prionitis*.
12	9 *Tegula brunnea*	1 *Botryoglossum*. 15 percent *Corallina chilensis*. 5 percent *Gastroclonium*. 5 percent *Gigartina canaliculatum*. 1 *Iridophycus* (ca. 20 percent coverage). 1 percent *Laurencia*. 50 percent *Phyllospadix*. 5 percent *Prionitis*.

General

As noted above, both the fauna and flora show considerable diversity. The diversity may arise in part from an ecotonal effect since Diablo Cove is near the well-known faunal and floral region of change at Point Conception (an ecotone is the region where two different habitats or environments overlap and species characteristic of each mingle with each other). Doubtless the diversity has also been abetted by the absence of human influence. Large numbers of legal sized black abalone in the intertidal region establish the pristine character.

One unusual feature that appeared to influence the distribution of the biota in a minor way was the discharge of fresh water from Diablo Creek in the center part of the Cove. Intertidally this results in the virtual disappearance of marine animals, and seaweeds are reduced to about four species (*Grateloupia*, *Prionitis*, *Cladophora*, and *Gigartina*).

The northwestern headland may cause some upwelling, although distributions are not influenced sufficiently to establish any clear relationship. Some of the deeper plants such as Nereocystis and Laminaria appear intertidally here, but protection from wave action might also be a factor. Underwater visibility was considerably better in the northern part of the Cove than in the southern, suggesting an influence by upwelling.

Surface drift was concentrated primarily in the southern and southeasterly portion of the Cove. Presumably this results more from the action of prevailing winds than from currents. A small accumulation of driftwood was also noted along the northern shore but virtually nothing was cast up over the large central region.

Nutritional Relationships

The economy of the Cove apparently depends heavily on productivity by attached algae. Herbivores noted were primarily grazing forms. While filter feeding animals were usually present in most areas, concentrations were typically sparse except in minor habitats such ts the upper portions of large pinnacles. Environments where productivity is largely by phytoplankton (bays, polluted waters, etc.) usually display massive development of encrusting filter feeding organisms on virtually all solid surfaces. While the various genera and species of fouling animals were adequately represented (Porifera, Coelenterata, Bryozoa, Urochordata, Tables 3 and 5), abundances were exceptionally low, even for an exposed rocky coastal environment. Phytoplankton concentrations are typically higher in spring than in fall and perhaps greater numbers of fouling organisms would be observed in late spring. Certainly the "seeds" for fouling are present, only the "stimulus" for massive development seems to be lacking.

The importance of attached algae in the economy of the Cove was the primary reason we devoted considerable attention to characterizing the species of these plants. As noted above, our lists of algal species are believed to be fairly complete and contain perhaps 90 percent of the seaweeds present. Probably all the species contributing significantly to plant productivity are represented in the lists (Tables 2 and 4). Principal groups poorly represented are epiphytic and endophytic forms that may have important physiological effects on their hosts, but are very minor in their contribution to total plant productivity.

The intertidal plant communities were so complex that it would be extremely difficult to identify the relative contributions to plant productivity by the principal species without a long and careful study. Fortunately, the intertidal area is small compared to the total area of the cove, so it is safe to assume that the major portion of productivity occurs subtidally. Although 52 plant species were recorded subtidally, only 12 appeared sufficiently abundant to be considered significant to subtidal productivity (*Desmarestia herbacea*. *Dictyoneurum*, *Egregia*, *Laminaria*, *Nereocystis*, and *Pterygophera* among the brown algae; *Botryoglossum*, *Calliarthron*, *Gigartina binghamiae*, *Iridopycus flaccidum*, and *Prionitis lanceolata* among the red algae; *Phyllospadix*, a flowering plant). Approximate distributions of these major species were recorded while swimming the transects (Figure 4). In areas not covered by transects it was assumed that distributions and species were similar to comparable depths observed along the transects. Underwater visibility was sufficiently clear so that plant distributions could be determined from our skiff down to depths of about 15 feet and spotchecks were made throughout the shallow portions of the Cove to verify the data presented in Figure 4. Distribution of the bull kelp, Nereocystis, could be determined from the surface since this plant forms a canopy in the upper layers.

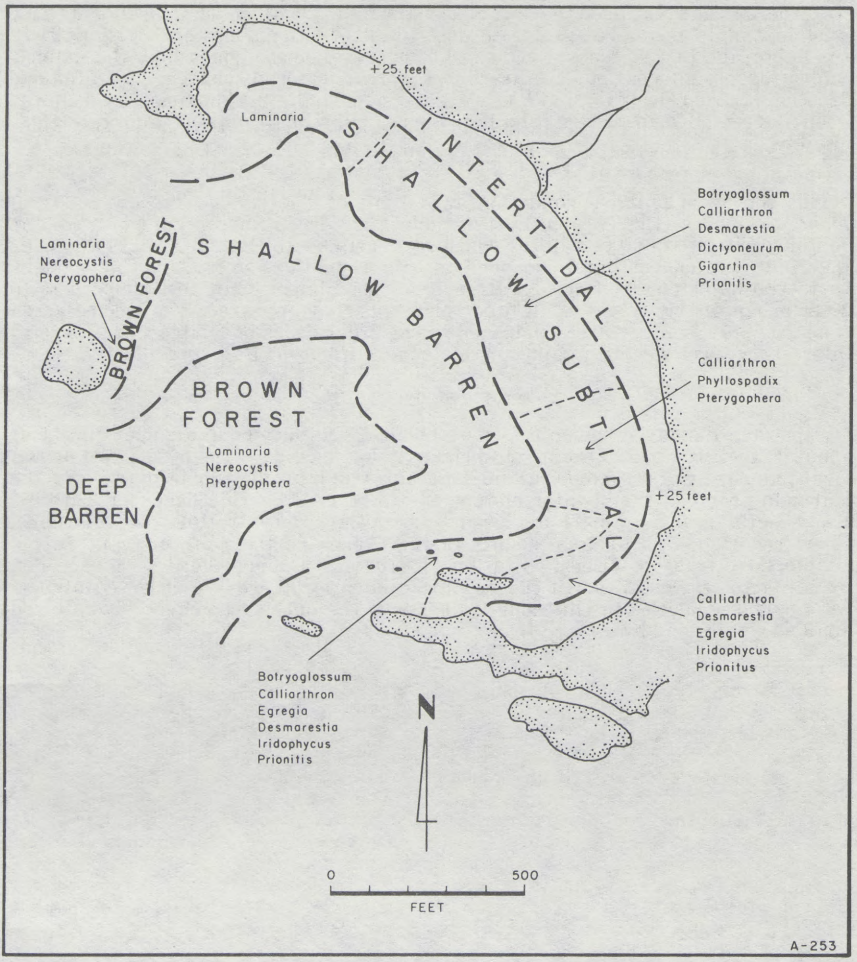

FIGURE 4. Zones and principal plant species observed within Diablo Cove, Nov. 1966.

Of particular interest was a broad belt of barren territory found throughout the Cove approximately between the depth contours of 10 feet and 25 feet, and at depths greater than 50 to 60 feet. This territory invariably displayed dense concentrations of urchins (primarily the giant urchin, *Strongylocentrotus franciscanus*, estimated to range from 5 to 50 per square meter). Urchins graze plants and the dense populations of these animals undoubtedly accounted for the barren condition of the bottom. Other herbivorous animals, including abalone, were scarce or absent in the urchin dominated territory. Both Ebert and Frances Clark mention that Diablo Cove is considered only as fair territory by abalone fishermen and the reason for the lack of excellence is probably the extensive area dominated by urchins.

Zonation

Zonation was well developed at all levels, both intertidally and subtidally. Existence of clearly defined zones was demonstrated by Transects A and B which showed similar associations appearing at approximately the same levels (Figures 2 and 3) even though the transect areas were separated by several hundred feet and represented quite different exposures to the sea. For present purposes, however, there is no great need to characterize the many small zones that undoubtedly exist in Diablo Cove. We prefer to describe five major zonal subdivisions that are important in the general ecology of the cove. These zones must be defined before discussing possible effects that a warm water discharge may produce. Proceeding from deep to shallow, we have named the major zones as follows: Deep Barren, Brown Forest, Shallow Barren, Shallow Subtidal, and Intertidal (Figure 4).

DEEP BARREN ZONE

This zone was found beyond the lower limit of *Laminaria-Nereocystis-Pterygophera* complex (the "Brown Forest" zone). The Deep Barren Zone occurred at depths greater than 60 feet in the southwest entrance to Diablo Cove. Plant cover was limited to encrusting forms such as *Lithothamnium*, except for the peaks of very large pinnacles. A sparse scattering of the giant urchin (est. density ½ to 2 per m^2) probably removed all other plants as they appeared. The Deep Barren zone was only a minor area compared to the other zones of Diablo Cove. Several interesting species were unique to this zone (*Allopora, Balanophyllia*).

BROWN FOREST ZONE

This zone displayed lower limits at about 50 to 60 feet and upper limits at about 25 feet. It was characterized primarily by dense growths of the two brown algal palm kelps. *Pterygophera* and *Laminaria* (Figure 5). Some patches of the bull kelp provided a midwater biotope that attracted benthic fishes (Figure 6). Many herbivorous animals achieved substantial concentrations in this zone. Ebert reported high abalone counts in the deeper portions of this zone in his Diablo Cove transect (Ebert's Station 1). Abalone numbers here were exceeded by only two other stations of the 18 sites studied by Ebert. We observed highest red abalone densities in this zone, and it was the only area where juvenile red abalone were found by us.

FIGURE 5. Silhouette angle showing the Brown Forest Zone as viewed from underneath. Stalks and blades of the palm kelps form a dense thicket throughout this zone.

FIGURE 6. View towards the surface showing a bull kelp plant extending up through the water column, attracting benthic fishes (blue rockfish) upwards.

SHALLOW BARREN ZONE

As mentioned above, the Shallow Barren Zone was dominated by dense concentrations of giant urchins. The zone lay approximately between the 10- and the 25-foot depth contours. Urchin concentrations were highest at the borders of the zone (Figure 7) ; apparently the animals were attracted by the plant food occurring above and below the zone. Some abalones occurred in the open at these borders, mingling with the urchins (Figure 8), but within the seaweed forests the abalones remained hidden in crevices and under rocks. In southern California we have found that abalones tend to occur in the open in daytime only when there is intense competition for food, as in migrating "urchin fronts". The abalones appear to be forced into daytime foraging in order to keep pace with the urchins.

SHALLOW SUBTIDAL ZONE

The lower limits of the Shallow Subtidal zone occurred between 10 and 15 feet while the upper border was arbitrarily considered to be the Intertidal zone. There was, however, no sharply defined upper border and in places the fauna and flora of the Intertidal extended into the Subtidal while in other spots the reverse was true. Likewise the two zones had many species in common. Nonetheless, the upper portions of the Intertidal were clearly different from the main part of the Shallow Subtidal zone. The Shallow Subtidal was considerably more complex than the Brown Forest zone and was subdivided somewhat arbitrarily into smaller regions according to the principal plant cover (Figure 4). Some of these principal plants occurred in mingled associations (Figure 9) and some occurred in almost pure stands of a given species (Figure 10).

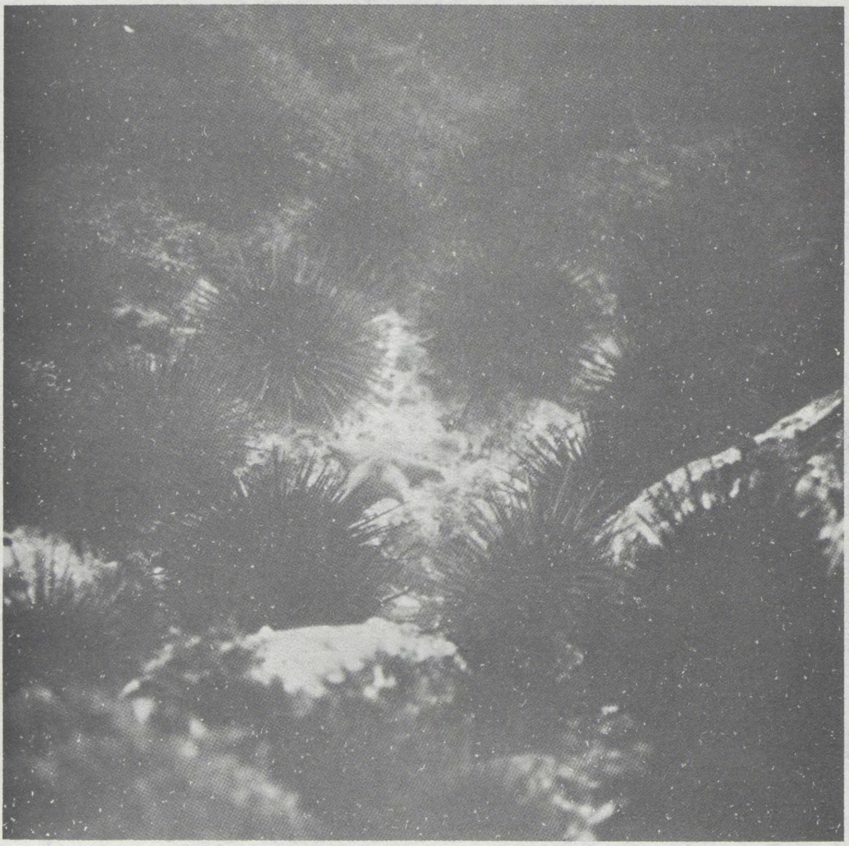

FIGURE 7. View along the boundary between the Shallow Subtidal Zone (background and lower left corner) and the Shallow Barren Zone (center and lower right). Note dense swarm of urchins, characteristic of the Shallow Barren Zone.

FIGURE 8. Vertical surface of boulder at boundary between the Shallow Subtidal Zone and the Shallow Barren Zone. Note red abalone exposed at top center. Abalone usually inhabit crevices during the day unless there is intense competition for food. Competitors in this case were giant urchins at bottom center. Stalk and holdfast of a palm kelp are in center, near abalone.

FIGURE 9. A thicket of feather boa kelp (*Egregia*) in the Shallow Subtidal Zone. The straplike blades are covered with clusters of an epiphytic green alga, sea lettuce (*Ulva*).

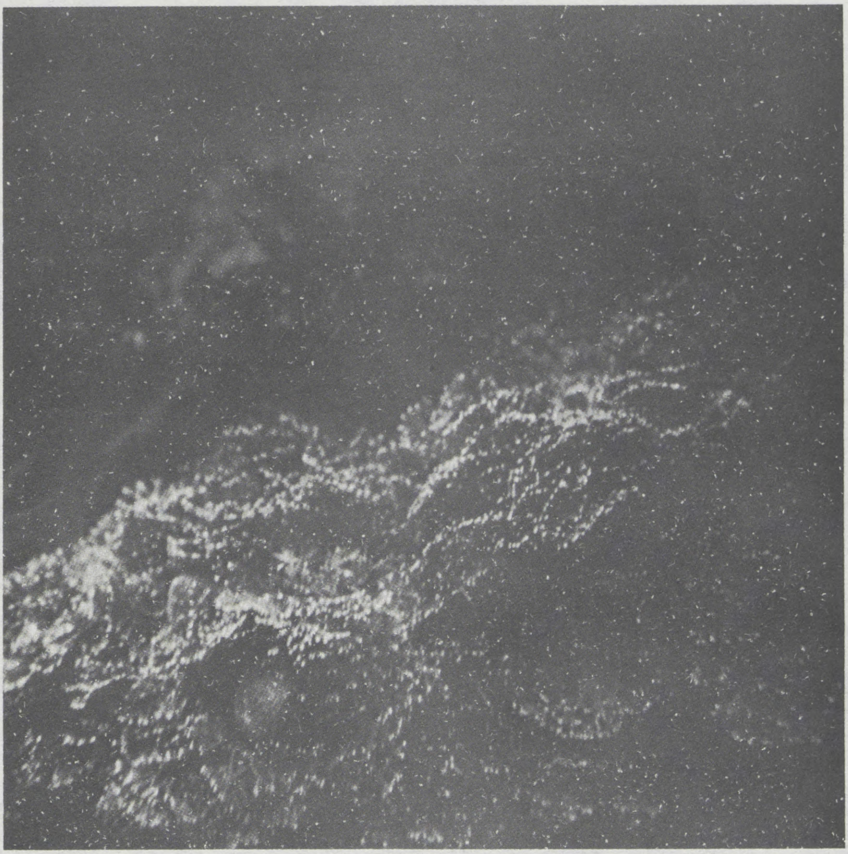

Figure 10. A patch of red coralline algae (*Calliarthron*) within the Shallow Subtidal Zone. Dense, luxurious foliage is typical of the Zone. Note grazing top snails (*Astraea*) slightly below and to the left of center.

The dense plant growths clearly offered abundant food and shelter for animals and the highly irregular bottom provided a maximal surface for attachment. Large boulder piles occurred near the southern border of the Cove in this zone and some provided deep crevice environments for abalones, urchines, etc. Some crevices were so large that they would be better described as small caves (Figure 11).

INTERTIDAL ZONE

As mentioned above, the Intertidal Zone graded uniformly into the Shallow Subtidal. Principal differences between the two were the species that appeared (and disappeared) in the upper regions of the Intertidal, and the thickness of the plant cover. Although most of the intertidal was completely covered by vegetation, the thickness of the cover was usually considerably less than found in the Shallow Subtidal. Probably this was the result of pruning action by surf. In consequence, there was undoubtedly significantly less seaweed standing crop in the Intertidal Zone and plant productivity per unit area of bottom may be substantially higher in the Shallow Subtidal. Nonetheless the Intertidal was clearly a luxuriant and productive zone.

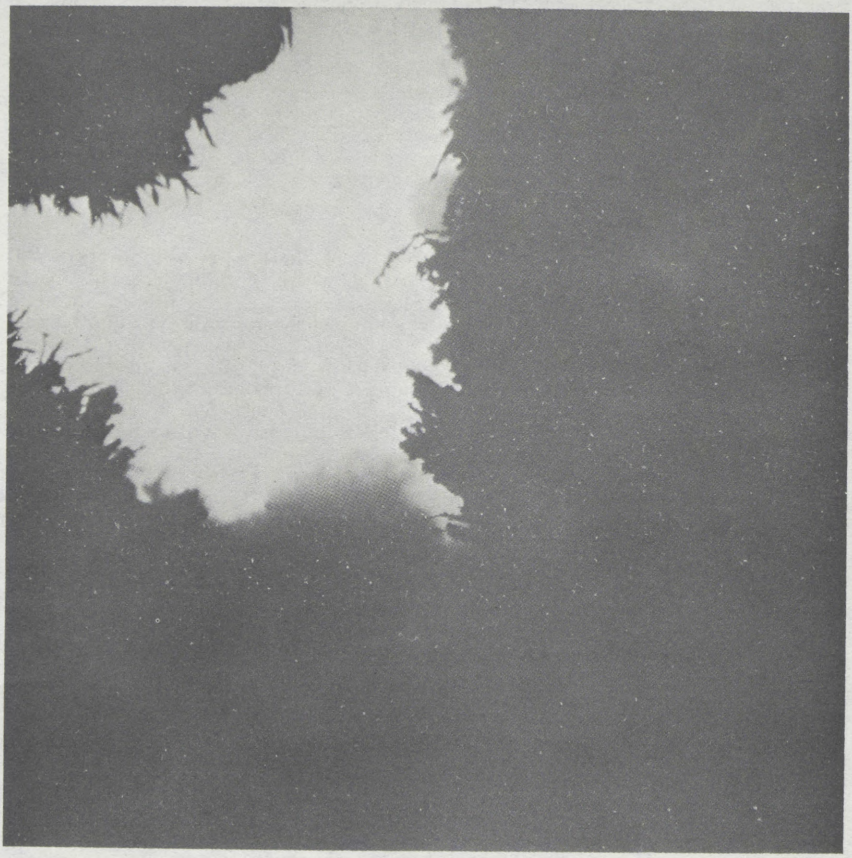

FIGURE 11. Large cavelike crevice environment common among boulder piles in shallow water at the southern margin of Diablo Cove.

POSSIBLE EFFECTS OF A WARM WATER DISCHARGE

When considering biological changes that may occur in a situation such as Diablo Cove, it is important to realize that the end result could be a richer, more dense association of organisms than now present. Changes in species composition do not imply that a barren area will develop or that standing crops will decrease significantly. While the writer has not had the opportunity of inspecting sites where warm water discharges have altered natural communities in a restricted area, it is clear from discussions with individuals who have studied such areas that they often support luxurious and highly varied associations of plants and animals. The nearness of Diablo Cove to Point Conception will probably make colonization by warm water organisms an easy matter, and a rich fauna and flora could very well comprise the ultimate community at Diablo Cove.

Species Changes

Many marine organisms can tolerate wide temperature fluctuations, and many survive continuous exposure to temperatures well above average values in their natural environment. As a crude means of assessing possible survival of Diablo Cove species after a warm discharge is initiated, we have identified those species known to inhabit warm waters in southern California (Tables 2, 3, 4, and 5). Such species included 25 intertidal plants (52 percent of the total), and 37 intertidal animals (58 percent), 16 subtidal plants (31 percent), and 47 subtidal animals (35 percent). While survival will certainly be influenced by the degree of temperature elevation and perhaps to a lesser extent by the rapidity of fluctuations, it is evident that there is a substantial component of species that can be labeled "potential survivors." It seems reasonable to predict that species sensitive to warm water will disappear and be replaced by species now present that can tolerate the change. With the passage of time other warm water species, currently absent, may appear as larvae or eggs are brought into the areas by ocean currents. In general terms, there will be an initial decrease in species diversity and standing crop, followed by a recovery of standing crop and probably a slower recovery of species diversity.

Ecological Imbalances

One problem remains to be considered, and this is whether appreciable ecological imbalances may arise during the initial period, while the biota is adjusting to the presence of warm water. Assuming there is a substantial loss of standing crop of living material, will the losses be equivalent among the various trophic levels (plant producers, herbivores, lower carnivores, higher carnivores, decomposers, etc.) or will losses be concentrated within one level, causing disruption of the entire system? If an imbalance develops, deterioration could be much more serious and extend beyond areas exposed to contact with warm water. Insufficient data exists to predict the possibilities of imbalance with any precision, but the potential for such an upset is believed to be present.

It seems likely that the large plant productivity occurring in the Intertidal and Shallow Subtidal Zones is not entirely consumed *in situ*. There is undoubtedly considerable transport of drift weeds from these zones to adjacent areas. As mentioned above, little drift was noted on the beach and probably the major portion of weeds torn loose moves seaward and is captured by the dense urchin populations lying just below the Shallow Intertidal Zone. During the diving operations, several urchins in the Shallow Barren Zone were broken open and appeared to be in a healthy nutritional state (starved urchins resorb yellow gonadal material and are easily identified as being in poor condition). The scarcity of algae in the Shallow Barren Zone suggests that the chief source of food for the healthy urchins is drift material.

Of the twelve plant species considered to be dominant producers in Diablo Cove (Figure 4), four are believed to be tolerant to warm water (Table 4). Of these four, *Egregia* and *Prionitis* are low on the scale of important plant producers in the Cove and *Calliarthron*, while quite abundant, is not nutritious since it is largely composed of inorganic skeletal material. *Phyllospadix* would be a truly major surviving species.

It is well established that urchin populations display massive migrations in search of food. If the large populations present in Diablo Cove are suddenly deprived of significant amounts of drift from higher levels, they can be expected to encroach on the Brown Forest Zone and to some extent into the Shallow Subtidal Zone (wave surge may limit migrations into shallow water to some extent). If this occurs, the effects on resident abalone may be far more severe than warm water damage. Severe competition for food would develop. The main portion of the temperature sensitive red abalone population lies at depths below 25 feet, and it seems unlikely that warm water would pose a serious threat to these animals. Urchins are apparently more mobile than abalone and are better able to catch drift. Many instances have been noted where urchins have survived while abalones disappeared, presumably dying of starvation.

The repercussions of an ecological imbalance might not extend beyond Diablo Cove, but it would be speculative to draw conclusions on this question at the present time. More information would be needed on plant and urchin distributions in adjacent areas before attempting further predictions.

Species Changes

It appears that some change of species is unavoidable. It should be noted, however, that thus far we have found no rare or new species in the shallow water regions of Diablo Cove. Biological effects would be reduced by engineering works that minimize changes in water temperature in the shallow water and intertidal regions.

Ecological Imbalance

It is believed that the likelihood of creating an ecological imbalance can be substantially reduced by a modest expenditure of effort and funds. As noted above, the principal cause for concern lies in the presence of a large population of giant urchins in the Shallow Barren Zone of Diablo Cove. Urchins are not utilized to any extent commercially, and they can be eliminated by techniques developed by the Kelp Habitat Improvement Project at the California Institute of Technology. It is believed that the populations in the Shallow Barren Zone of Diablo Cove could easily be reduced to insignificant concentrations.

If urchin populations were destroyed, vegetation would develop almost immediately in the barren areas. An excellent cover would require six months to one year for growth. If control of the urchin populations is undertaken, quicklime treatments should be conducted as far in advance of initial power plant operations as possible, to allow adequate development of vegetation and stabilization to occur.

Defining Kelp Areas

Assessing the biological effects of power plant operations will be facilitated on defining the major kelp areas in the vicinity of Diablo Cove. The principal species of bed-forming kelp observed was the bull kelp, *Nereocystis*. This plant elaborates large amounts of tissue at the sea surface by means of a flotation device, so the distribution of the species can be determined without having to dive. Aerial photography has proved very useful in charting kelp beds in southern California and would be the logical method for mapping beds near Diablo Cove. *Nereocystis* is a cold water alga and would be expected to suffer deterioration if exposed for long to warm temperatures. It should prove very useful to indicate any adverse effects of power plant operation at or near Diablo Cove.

Adequate definition of kelp areas will require several series of aerial photographs. Beds vary in extent with season and from one year to the next. The task of establishing the location and extent of beds and the variations in size is in progress. The author had an opportunity recently to fly near Diablo Cove and was able to shoot oblique photographs of the coast, from which a rough map of the major kelp areas was sketched (Figure 12). This map should not be considered at all adequate for defining kelp areas because it is almost certainly quite inaccurate due to the obliquity and distance away of the photos (Figures 13 to 19). It does, however, provide a concept of the complex distribution patterns of kelp beds and establishes a base for additional work.

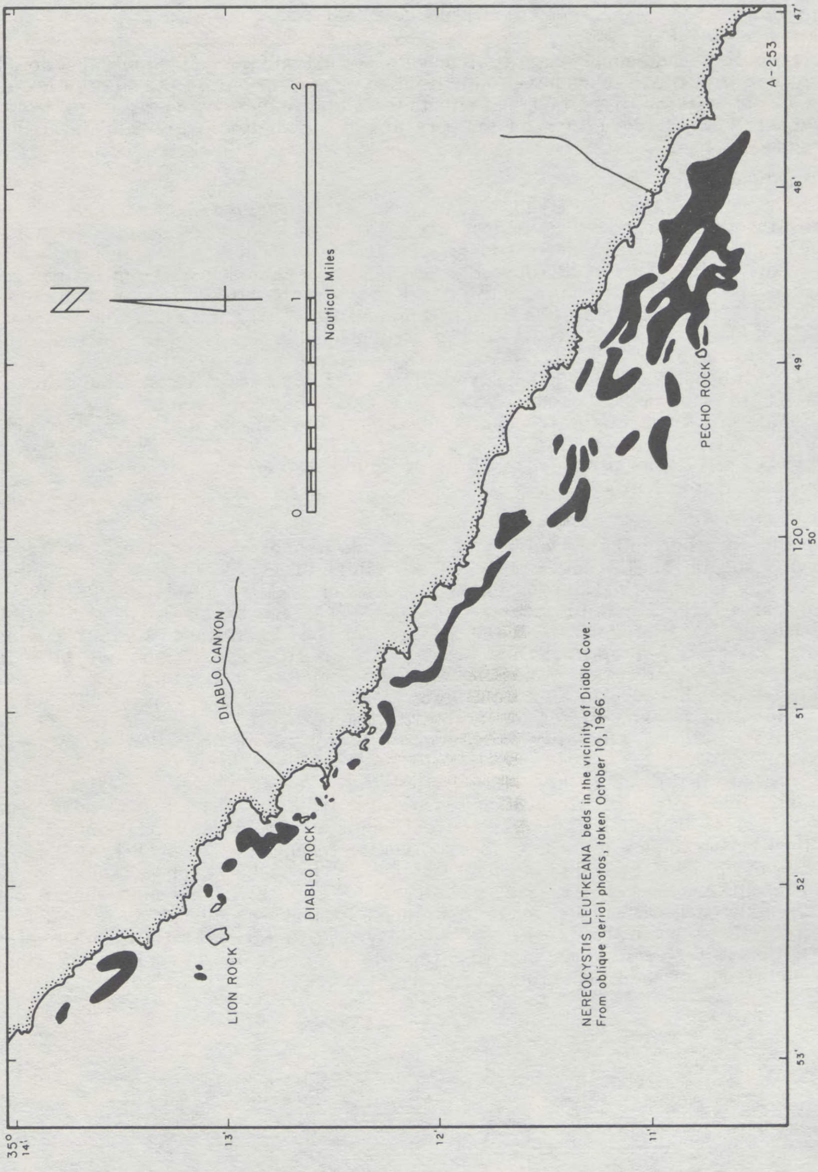

FIGURE 12. Chart of kelp beds in the vicinity of Diablo Cove.

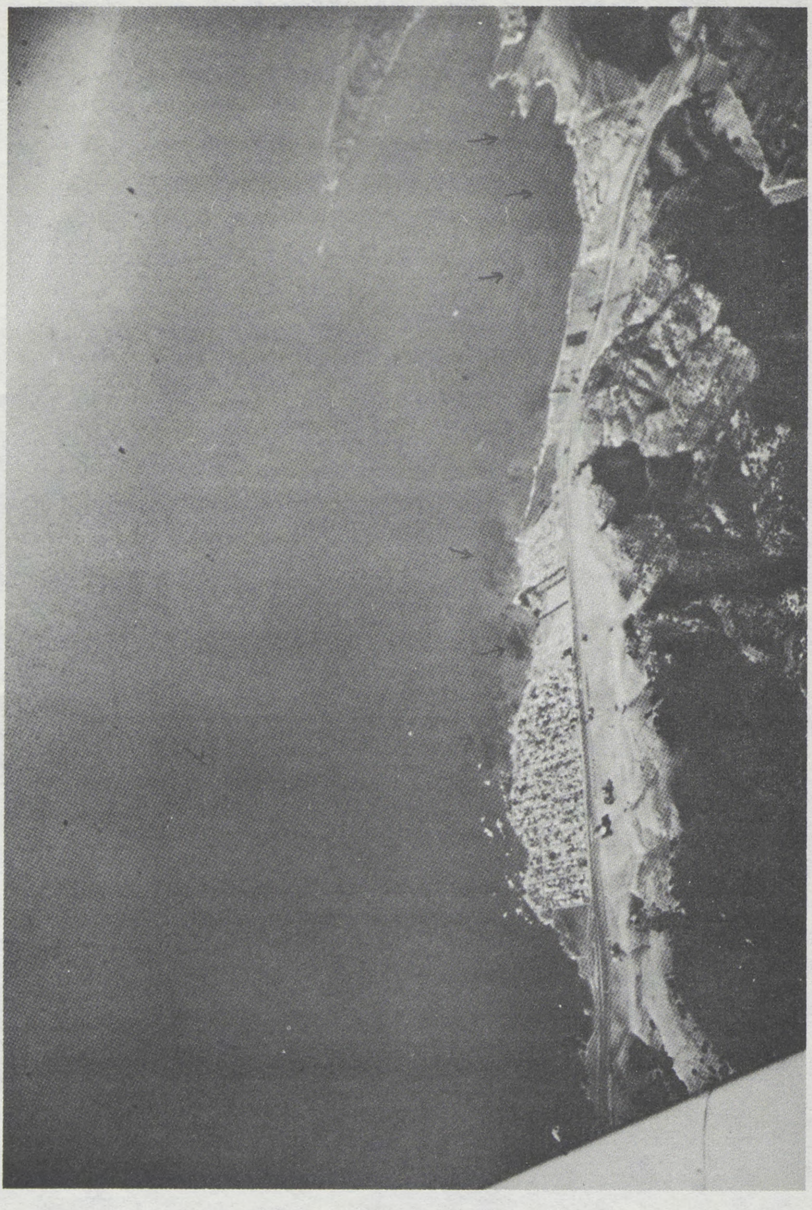

FIGURE 13. Black and white enlargement of a kodachrome slide, showing kelp beds in San Luis Obispo Bay and off Shell Beach, October 10, 1966.

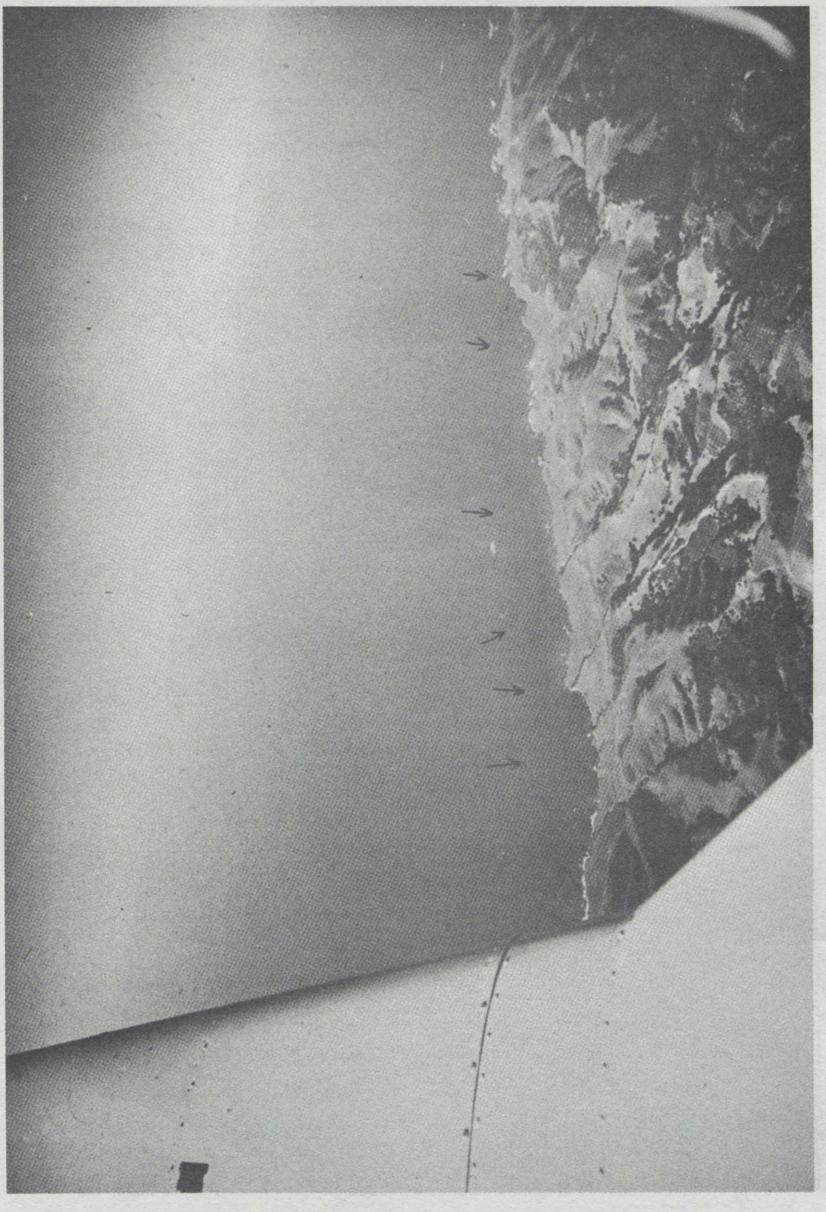

FIGURE 14. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) just north of Point San Luis, October 10, 1966.

FIGURE 15. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) near Pecho Rock, October 10, 1966.

FIGURE 16. Black and white enlargement of a kodachrome slide showing offshore kelp near Pecho Rock (arrows), October 10, 1966

FIGURE 17. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) between Pecho Rock and Diablo Cove, October 10, 1966.

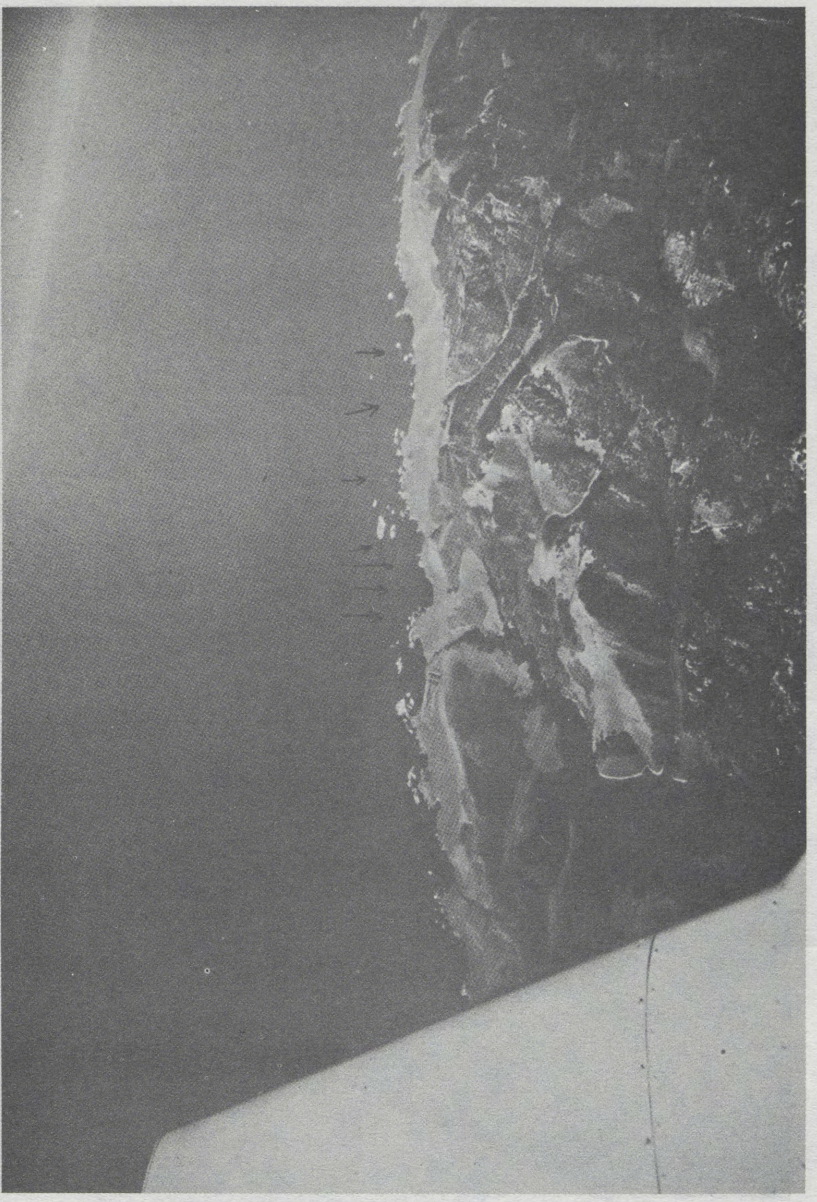

FIGURE 18. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) near Diablo Cove, October 10, 1966.

FIGURE 19. Black and white enlargement of a kodachrome slide showing offshore kelp (arrows) north of Lion Rock, October 10, 1966.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cheerful assistance provided by James Adams of Pacific Gas and Electric Company. The amount of work that could be accomplished was significantly increased by Mr. Adams' efforts. Likewise, thanks are due to Barbara B. North for assistance in collecting and identifying, and in typing manuscript. The completeness of our algal species lists is largely due to her skill.

SUMMARY

1. Diablo Cove lies on an exposed rocky coast. Bottom topography is extremely irregular. Measurements and plant distributions indicated submarine illumination is probably good. Circulation and water movements are well developed.

2. A highly diversified species assemblage was found. Intertidally 44 plant and 64 animal species were observed while subtidally the numbers totaled 52 plants and 134 animals. It is believed that the list of plant species is fairly complete but possibly as few as half of all animal species present were recovered.

3. The high species diversity may result from an ecotonal effect and from the relative freedom the area has enjoyed from human influences.

4. Attached plants appear to be the chief source of organic productivity in the area. Grazing animals were much more abundant than filter feeders. Consequently considerable attention was given to identifying principal plants and their distributions within the Cove.

5. Five major zones were described. These were a "Deep Barren" zone, a "Brown Forest" zone (comprised principally of larger brown algae), a "Shallow Barren" zone (dominated by grazing urchins), a "Shallow Subtidal" zone, and an "Intertidal" zone.

6. The extent and consequences of a warm water discharge are discussed. The most likely result is believed to be a moderate decrease in species diversity and replacement of cold water forms by warm water organisms. Such changes may extend as deep as the Shallow Subtidal Zone. Of greater concern is the possibility of ecological imbalance. The consequences of upsetting trophic relations in the Cove are discussed.

7. Possibilities for avoiding species change and ecological imbalance are discussed. It is suggested that control of urchins in the Shallow Barren Zone would be an excellent precaution for avoiding imbalance.

8. The need for establishing the positions and extent of nearby kelp beds is mentioned. It is believed that the beds constitute an excellent tool for monitoring adverse influences from a warm water discharge.

STATEMENT AND ADDITIONAL MATERIAL SUBMITTED BY PACIFIC MARINE FISHERIES COMMISSION

PORTLAND, OREG., *May 6, 1968.*

All Members of Congress From the State of Alaska, California, Idaho, Oregon, and Washington.

MY DEAR SENATORS AND CONGRESSMEN: The attached Resolution No. 6, "Thermal Plants To Be Licensed by FPC," was adopted by the Pacific Marine Fisheries Commission at its annual meeting on December 1, 1967.

The problems of discharging heated water into and the consequent likelihood of thermal pollution of this Nation's fresh and estuarial waters are becoming increasingly menacing and imminent. At present, over 80 percent of the total electric power produced in the United States originates from thermal electric plants, and the prospects are that this percentage will increase rapidly.

Site selections are being made and announced without benefit of adequate discussion or clearance by the appropriate state or federal pollution control or fish and wildlife agencies. This situation arises because of lack of centralized authority to license thermal electric plants. Anthony Netboy's book, "The Atlantic Salmon, a Vanishing Species?" in the chapter on "Dissipation of the French Salmon Resource," contains the following statement regarding divided or haphazard authority: "Where so many bureaux are involved conflicts are naturally generated and vested interests will triumph at the expense of natural resources."

A U.S. Department of the Interior News Release of November 22, 1966 quotes Under Secretary of Interior Dr. Stanley A. Cain as follows: "We do not have firm control on thermal pollution caused by steam electric plants because they are not subject to Federal license. Nuclear plants, however, require a license from the Atomic Energy Commission. We regularly report to A.E.C. on probable effects on fish and wildlife by licensed nuclear plants. But the Atomic Energy Commission has authority to consider only radiological effects on the environment, and no authority to consider the effects on fish and wildlife unless they are radiological effects. In other words, A.E.C. cannot take into account the thermal pollution of water unless it is a radiological pollution. This can be very difficult in the years ahead as nuclear energy takes over more and more of the nation's power load."

Dr. Cain had the following to say about the responsibilities of the Federal Power Commission. The FPC requires an applicant for a license to submit an Exhibit S which must state, in some detail, the effect of a proposed project on fish and wildlife resources and describe "the methods to be incorporated in the project, not only to preserve and protect fish and wildlife but also to enhance them."

However, PMFC feels that the FPC's present jurisdiction is too limited. George R. Snyder, Fishery Research Biologist, U.S. Bureau of Commercial Fisheries, Seattle, before the Oregon Division of the Izaak Walton League of America, said in Portland on February 17, 1968: There is needed "the establishment of strong legislation that will provide for compulsory review of each proposed site—by qualified fish and wildlife agencies" . . . "A review is not required at the present time." "Permission is given to construct and operate thermal nuclear electric plants in the United States today solely by the Atomic Energy Commission." . . . "the Federal Power Commission does not have authority to review thermal electric plants (either fossil fuel or nuclear), unless the plant is associated with or an integral part of a hydro facility. This lack of authority exists even when over 80 percent of the total electric power produced in the United States originates from thermal electric plants."

PMFC feels that since FPC has the responsibility to see that the public is best served in regard to hydro-power projects that come under its purview and since the distribution of natural gas also comes within FPC's purview, that FPC's licensing authority should extend to all non-federal and private power projects regardless of the primary energy source (hydro, fossil or nuclear energy) used to run the projects.

Enclosed for your information are copies of the following which illustrate the national concern about the threat of thermal pollution:

Editorial from Oceanology International, Jan/Feb. 1968, "The Thermal Pollution Threat."

News Release of Pacific Northwest Pollution Control Council, February 27, 1968.

"Thermal Pollution Views," a resolution from the Northeastern Division of the American Fisheries Society published in Sport Fishing Institute Bulletin 193, April 1968.

"Play Fair Ball," a letter to the Editor of the Portland *Oregonian*, April 29, 1968.

Respectfully,

LEON A. VERHOEVEN,
Executive Director.

P.S.—It has been suggested that S. 2889 or H.R. 14971, the "Electric Power Reliability Acts," might be conveniently amended by words to the effect: Any water diversions for the development of thermal energy shall be subject to the regulatory authority of the Federal Power Commission.

[Enclosures]

PACIFIC MARINE FISHERIES COMMISSION—RESOLUTION NO. 6—"THERMAL PLANTS TO BE LICENSED BY FPC"

Whereas, thermal plants, especially nuclear plants, for the generation of electric power are expected to increase rapidly in number, and

Whereas, it is anticipated that many of these plants will be located on bodies of water where the use of water for cooling will have significant effect on the aquatic resources therein, and

Whereas, the present system of licensing and control of thermal power plants does not provide adequately for the protection of these resources, and

Whereas, the Federal Power Commission has the responsibility to see that all resource values, including fish and wildlife, are protected at projects proposed under its licensing authority; *Now, therefore, be it*

Resolved, That the Pacific Marine Fisheries Commission urges Congress to require all thermal plants to be licensed by the Federal Power Commission.

Adopted at Annual Meeting, Gleneden Beach, Oregon, December 1, 1967.

[Oceanology International January–February 1968]

EDITORIAL

THE THERMAL POLLUTION THREAT

The increasing number of nuclear power plants is posing a serious new threat to the ecology of the nation's rivers, lakes and estuaries. Great quantities of heated water being discharged from these plants will cause a growing thermal pollution problem.

The deluge of heated water resulting from the cooling process is raising water temperatures, thereby killing cold-water fishes, encouraging the growth of algae, and preventing waterways from cleansing themselves.

At present, nuclear installations provide only a fraction (about 1%) of the nation's 260 million kilowatts of generating capacity. By 1980, however, the nuclear share is expected to constitute 30% of an estimated 530-million kilowatts.

Greater power output will be accompanied by accelerated thermal pollution. The discharge of warm water from generating plants may more than double—from 48-trillion to 108-trillion gallons—during this same period.

Nuclear power plants produce far more thermal pollution than conventional coal-, oil-, and gas-fueled generating facilities. For safety reasons, nuclear installations must operate with lower steam pressure. As a result, nuclear plants are less efficient than other plants and they discharge about 50% more waste heat through their condenser cooling systems.

Because of the threat of increased thermal pollution, Sen. Edmund S. Muskie (D-Me.) has called upon the Atomic Energy Commission to insist on built-in safeguards before granting construction permits for nuclear power plants. He also would like to see Congress enact more stringent antipollution legislation.

The AEC has stalled on the imposition of restrictions on nuclear thermal pollution. It claims that it does not have the authority to regulate non-radiological hazards. At the same time, the agency is reluctant to saddle the infant nuclear power industry with costly water-cooling restrictions when other types of power plants escape such regulations because they do not have to obtain federal licenses.

It is possible to control thermal pollution through the use of one or more huge cooling towers. But such towers are expensive. Utility companies would have to add $2 billion or more to the contemplated $19 billion investment they plan to make in nuclear power plants by 1980.

We recognize the additional costs involved in eliminating thermal pollution. However, the editors of *Oceanology International* believe that restrictions must be imposed on *both* nuclear and conventional power plants if the nation's water resources are to be saved.

Antipollution legislation should be adopted that will force utilities to correct *all* sources of thermal pollution. Meanwhile, the AEC should withhold all nuclear construction licenses until provisions are incorporated to control the menace of thermal pollution.

[News Release, Pacific Northwest Pollution Control Council]

Pacific Northwest Pollution Control Council Acts on Thermal Pollution Problems

At a meeting held in Spokane, Washington, on Monday, February 26, the Pacific Northwest Pollution Control Council expressed grave concern regarding the water pollution which may result from the fifteen thermal nuclear power plants projected for construction in the Pacific Northwest in the next twenty years, according to Roy M. Harris, chairman of the Council.

Attending the meeting were representatives of the Federal Water Pollution Control Administration; the pollution control agencies of the States of Idaho, Montana, Oregon, and Washington; and the Canadian Health Department.

The Council observed that region-wide studies of thermal nuclear power plant site plans and the proposed handling of cooling water discharges have been based almost solely on the desire to keep to an absolute minimum the total cost of the resulting integrated hydro-thermal power system projected for the Pacific Northwest. The Council holds that studies made on that basis cannot provide full protection to the environment.

The Council also noted that selections of two specific sites on the Lower Columbia River are announced without the benefit of adequate discussions with or clearance by the appropriate State and Federal pollution control agencies.

Because of the magnitude of the potential water pollution problems, the Council agreed that a task force on environmental quality control should be formed immediately to develop guidelines for siting nuclear power plants in the Pacific Northwest before any additional site selections are made.

The Council members agreed that the guidelines should include the following:

1. Thermal nuclear power plants should provide the highest and best practicable treatment of wastes to prevent any degradation of existing water quality, as required by the water quality standards adopted by the States and approved by the Secretary of the Interior.
2. From the outset, thermal nuclear power plants located on inland waters should provide facilities for complete off-stream cooling.
3. First consideration should be given to locating thermal nuclear power plants along open coastlines where waste heat can be dissipated into the ocean with minimum effects on the environment.

Council members attending the Spokane meeting include Vaughn Anderson. Boise, Idaho, Department of Health; Claiborne Brinck, Helena, Montana Board of Health; E. Jack Weathersbee, Portland, Oregon State Sanitary Authority; Roy M. Harris, Olympia, Washington Water Pollution Control Commission; R. F. Poston, Portland, Federal Water Pollution Control Administration; and Stanley Copp, Vancouver, B. C., Canadian Department of Health.

[From the Sport Fishing Institute Bulletin 193 April 1968]

THERMAL POLLUTION VIEWS

At its recent 17th annual meeting (January 16, 1968) in New Hampshire, the Northeastern Division, American Fisheries Society, adopted the following resolution, with respect to "exercise of authority over the effects of thermal pollution":

Whereas the waters of the Northeastern States are major elements in the rapidly expanding tourist and recreation industry and public demand for water related recreation is great; and

Whereas these waters are increasingly proposed for usage as the cooling agent in the rapidly expanding development of steam electric stations; and

Whereas there is increasing concern regarding the Atomic Energy Commission policy of granting licenses for nuclear-fuel steam electric stations and the Federal Power Commission for fossil-fuel steam electric stations without giving due consideration to the effects of heated effluents on water quality standards and environmental changes detrimental to fishery resources: Now, therefore, be it

Resolved, That the Northeastern Division of the American Fisheries Society does hereby request and urge that the Federal Water Pollution Control Administration exercise its authority to control water pollution affecting interstate and tributary waters under the Water Quality Act of 1965 over the effects of thermal pollution emanating from fossil-fuel and nuclear-fuel steam electric stations; and, be it further

Resolved, That copies of this resolution be transmtted to the Secretary of the Interior, to the Assistant Secretary for Water Pollution, the Chairman of the Appropriations Committees of the Congress of the United States, the Congressional Delegates of the States encompassed by the Northeastern Division and to the International Association of Game, Fish and Conservation Commissioners.

[From the Oregonian April 29, 1968]

PLAY FAIR BALL

To the Editor: Your recent editorial on hot water in the Columbia from pending nuclear power plants does not go far enough to alert the public to the extremely serious problem.

By the year 2000 there will be 30 nuclear power plants in the region of 1 million kw. capacity, each using 2,000 cubic feet of water per second and raising the temperatures 16 degrees Fahrenheit. Each plant will use every day 15 times the amount of water consumed in the City of Portland on an average day. All 30 plants will use as much water as 60 per cent of the average minimum flow of the Columbia River at the mouth.

No matter where this flood of warm water is spread, over the Columbia River or into other Northwest rivers, the effects can be very harmful to fish and can change substantially other features of Northwest life.

It is therefore crucial to protect all of us that the first such plant to be built by Portland General Electric must either use the most effective method of cooling water—the use of cooling towers—or locate away from the Columbia River along the ocean. If PGE is permitted to get away without the use of cooling towers, then Cowlitz and Clark County PUD's will ask for the same privilege for their plant a few miles away from PGE's, and every other of the 28 nuclear power plants can claim the same rights. In England, cooling towers are required at inland locations.

Federal and state regulations must not permit favoritism to one company. You can't control sewage pollution, fires, air pollution and automatic safety by giving any individual or company an exception. Enforcement must be universal and impartial.

The extra costs of electric power from the use of cooling towers are less than 5 per cent, according to qualified engineers. The Northwest can pay 10 per cent or more and still have the lowest cost power in the U.S.A.

This is no time for pussy-footing. Our editorial writers, our water pollution control authorities and our electric utilities had better play fair ball with the public on this issue from the start.

MATERIAL SUBMITTED BY AMERICAN FISHERIES SOCIETY

AMERICAN FISHERIES SOCIETY,
Washington, D.C., September 30, 1968.

GENTLEMEN: The attached resolutions were adopted by the American Fisheries Society, at its 98th Annual Meeting in Tucson, Arizona, on September 9, 1968. Because of the large number of copies necessary for distribution, this letter and the resolutions were duplicated.

Since the prestige of the American Fisheries Society is measured by the quality, not the quantity, of its resolutions, the Society's policy is to adopt resolutions, other than those relating to internal Society matters, only on important issues of broad national or international interest where an expression of the views of the membership can be expected to carry weight. The society has decided to use all reasonable available means to stimulate action on matters recorded in its resolutions.

The American Fisheries Society will hold its 99th Annual Meeting in 1969 at the Roosevelt Hotel in New Orleans, with the Louisiana Wildlife and Fisheries Commission as host. The Society will meet September 10–11–12, and the International Association of Game, Fish and Conservation Commissioners will meet September 8–9–10. The Centennial Celebration of the American Fisheries Society will be held during the week of September 13, 1970, in conjunction with the 60th Annual Convention of the International Association of Game, Fish and Conservation Commissioners, at the Waldorf Astoria Hotel in New York City. Plans for all these meetings are already being formulated. We extend a most cordial invitation to you and to your friends in hopes that you will be able to attend each of these outstanding meetings.

Because the Annual Report of the Committee on Names of Fishes, affirms the continued use of Greenland halibut for *Reinhardtius hippoglossoides*, the entire Committee Report has been reproduced here.

Sincerely yours,

ROBERT F. HUTTON,
Executive Secretary.

[Enclosures]

RESOLUTION NO. 1—PREVENTION AND CONTROL OF THERMAL POLLUTION

Whereas, an increasing proportion of the demand for electrical energy in the United States is being met by steam generating plants using fossil fuels and atomic energy, and which employ water as a cooling agent; and

Whereas, the direct and indirect effects of heated water discharges on fishes and other aquatic organisms are inadequately known; and

Whereas, additional information on these effects is desperately needed to adequately determine these effects and to properly license and regulate these installations: Therefore be it

Resolved, By the American Fisheries Society that immediate studies and research in the field of thermal effects with additional substantial industrial financial support, be undertaken so that a better understanding of the effects of heated water discharges upon fishes and other aquatic organisms is obtained: And be it further

Resolved, That passage of legislation similar in purpose to H.R. 16852 (90th Congress), which would provide for Federal licensing of all features of both fossil-fueled and nuclear-fueled power plants be urged, that each license incorporate the views and recommendations of the Department of the Interior and the appropriate state game and fish agency on ways and means to minimize the adverse effects of such plants on the environment: And be it further

Resolved, That the Federal Water Pollution Control Administration exercise its full legal authority to control water pollution in interstate and tributary waters as provided in the Water Quality Act of 1965 and with special regard to thermal effects emanating from fossil-fueled and nuclear-fueled power plants: And be it further

Resolved, That copies of this resolution be transmitted to the Secretary of the Interior, to the Assistant Secretaries for Water Pollution Control and for Fish and Wildlife and Parks; to the Federal Power Commission; to the Atomic Energy Commission; and to the Chairmen of appropriate committees of the Congress of the United States.

Submitted by: North Central Division, Northeastern Division, American Fisheries Society.

RESOLUTION NO. 2—PROPOSING THAT THE MISSOURI RIVER BETWEEN FORT PECK RESERVOIR AND FORT BENTON, MONTANA, REMAIN FREE OF ADDITIONAL IMPOUNDMENTS

Whereas, the American Fisheries Society is composed of persons and organizations who subscribe to the philosophy that in some instances the recreational needs of a State, a Province, a region, and a nation may best be served by maintaining portions of major river systems in an unaltered condition; and

Whereas, that stretch of the Missouri River between the upper end of Fort Peck Reservoir and the community of Fort Benton, both in the State of Montana, constitutes such a valuable and irreplaceable resource; Therefore be it

Resolved, By the American Fisheries Society that the above named portion of the Missouri River remain in its free-flowing condition, free from impoundments; and be it further

Resolved, That copies of this resolution be sent to the Chief, U.S. Army Corps of Engineers; to the Secretary of the Interior, to the Assistant Secretaries for Water and Power Development and Public Land Management; to the Chairman, Committees for Public Works, Senate and House of Representatives, Congress of the United States; and to the Governor, State of Montana.

Submitted by: North Central Division, American Fisheries Society.

RESOLUTION NO. 3—PROTECTION AND DEVELOPMENT OF ESTUARIES

Whereas, the estuaries of the North American continent constitute a limited, irreplaceable natural resource of extremely high value to the welfare of man and the living resources on which he depends; and

Whereas, more particularly, these estuaries are essential to the production of many fisheries of sport and commercial value; and

Whereas, the rate of dredging and filling these waters for purposes of navigation, mining, and industrial and residential development is rapidly increasing; and

Whereas, pollution of these waters, including wastes from industry, pesticides, untreated and improperly treated sewage, and silt are adversely affecting the quality of estuarine environments; and

Whereas, the inflows to these estuaries are being depleted particularly in water short areas, by upstream uses and diversions, thus altering the salinity gradients and dependent ecologic complexes of these estuaries: Therefore be it

Resolved, By the American Fisheries Society that all coastal States and Provinces are hereby urged to establish regulations and other safeguards to protect and preserve estuarine habitat and assure the orderly multipurpose development of estuaries: And be it further

Resolved, That the States, Provinces, and Federal agencies are hereby urged to cooperate fully among themselves and assume fully their individual responsibilities to the end that the welfare of the estuaries are adequately maintained in the public interest: And be it further

Resolved, That copies of this resolution be sent to the Governors of each coastal State; the Secretary of the Interior; the Chief, U.S. Army Corps of Engineers; the Premiers of the Provinces of Canada; the Minister of Fisheries of Canada; and to appropriate officials of other North American sovereign States.

Submitted by: Western Division, American Fisheries Society.

Resolution No. 4—Clearance of Chemicals Needed in Fishery Management

Whereas, the United States Department of Agriculture and the Food and Drug Administration are closely scrutinizing all drugs, pesticides and various chemicals including those used by fishery and game managers; and

Whereas, many compounds are essential in the operations conducted by the fish and game managers in the development and improvement of fish and game populations; and

Whereas, even though several of these compounds have been in use for several years and no harmful effects have been demonstrated and research has been conducted showing no deleterious effects, they still lack clearance by the USDA and FDA: Therefore be it

Resolved, By the American Fisheries Society that the Department of Agriculture, the Food and Drug Administration, and the U.S. Fish and Wildlife Service, reach an early accord on the research to be done and the use of chemicals needed in the management of fish and wildlife populations; and be it further

Resolved, That copies of this resolution be sent to the Secretary of Agriculture; the Secretary of the Interior, the Commissioner, U.S. Fish and Wildlife Service, the Commissioner, Federal Water Pollution Control Administration; and to the Commissioner, Food and Drug Administration.

Submitted by: Dr. Edward Schneberger.

Resolution No. 5—Methods of Economic Analysis for Recreation, Fish and Wildlife

Whereas, it has become common practice to evaluate recreation and fish and wildlife resources in monetary terms; and

Whereas, the classical pricing methods have been used to establish monetary values for outdoor recreation; and

Whereas, classical methodology may be inappropriate for setting such values because these values are aesthetic and intangible as well as economic; and

Whereas, additional research, considering both social and ecological values should be undertaken: Now, therefore, be it

Resolved, That the American Fisheries Society supports the concept of expanding the research effort toward improving current methodology: And be it further

Resolved, That the Society encourages governmental agencies to develop their own capability in this field so that this research may be properly guided and implemented: And be it further

Resolved, That copies of this resolution be sent to the fish and game departments of all states; to the Commissioners U.S. Bureau of Reclamation and the U.S. Fish and Wildlife Service, the Director, Bureau of Land Management; to the Chief, U.S. Army Corps of Engineers; the U.S. Department of Agriculture; to the Minister of the Canada Department of Fisheries and Forestry, and Ministers of the Natural Resources Departments of each Canadian Province.

Submitted by: Western Division, American Fisheries Society.

Resolution No. 6—Endorsement of Water Quality Criteria for Fish and Other Aquatic Life Recommended by the Subcommittee of the National Technical Advisory Committee on Water Quality Criteria

Whereas, a majority of the Subcommittee for fishes, other aquatic life, and wildlife, of the National Technical Advisory Committee on Water Quality Criteria, appointed by the Secretary of the Interior to advise him, were selected from U.S. and Canadian members of the American Fisheries Society as recognized scientific authorities on the environmental requirements of fish and aquatic life, the Subcommittee Chairman being an Honorary Life Member of the Society; and

Whereas, those same aquatic scientists, all distinguished members of the American Fisheries Society, have accomplished a truly herculean task in synthesizing and reducing the pertinent knowledge into a significant and useful document clearly setting forth, to the extent presently known, the quality of water that must prevail to permit continuing production of aquatic life in abundance for all beneficial uses by mankind; and

Whereas, certain judgments that have been made in the absence of precise and adequate data with respect to various criteria reflect the most authoritative scientific judgments currently available, and must therefore be accorded maximum credibility over alternatives that might be proposed by others less qualified, pending the initiation and outcome of specific research on these matters already envisioned and set forth by this same group of distinguished Society members, in their related supplementary report to the Federal Water Pollution Control Administration on "Research Needs For Water Quality Criteria" for fish and other aquatic life and wildlife: *Now, therefore be it*

Resolved, That the American Fisheries Society, the principal scientific society in the aquatic life resource field, assembled in its 98th Regular Annual Meeting this 9th day of September, 1968, at Tucson, Arizona, does herewith endorse the Report of the National Technical Advisory Committee on Water Quality Criteria as it applies specifically to fish and other aquatic life and urges, subject to continuing refinement in the light of local knowledge and new findings that will result from future research, that the related Subcommittee recommendations be officially adopted by the FWPCA as reflective of the best available current scientific facts and judgments; And be it further

Resolved, That the American Fisheries Society does herewith gratefully thank and commend for their dedicated efforts the following distinguished Society Members, who gave unstintingly of their time and effort on behalf of the Society's objectives to the benefit of all American citizens, as Chairman and Members of the Subcommittee on Fish, Other Aquatic Life, and Wildlife, National Technical Advisory Committee on Water Quality Criteria:

Dr. Clarence M. Tarzwell, Chairman
Dr. Bertil G. Anderson
Mr. George E. Burdick
Dr. Philip A. Butler
Dr. Oliver B. Cope
Dr. Richard F. Foster
Dr. F. E. J. Fry
Dr. Arden R. Gaufin
Mr. Eugene P. Haydu
Mr. Crosswell Henderson
Dr. J. M. Lawrence
Dr. Donald I. Mount
Dr. D. I. Rasmussen
Mr. Eugene W. Surber
Mr. Arthur N. Woodall
Dr. Harold Berkson

And, as effective Society liaison on the Subcommittee for Recreation and Aesthetics, Mr. Roy K. Wood.

And, as effective Society liaison on the Subcommittee for Water Supplies, Dr. Harold W. Wolf: And be it further

Resolved, That copies of this resolution be sent to the Secretary of the Interior, the Commissioner of the Federal Water Pollution Control Administration, and the members of the American Fisheries Society commended above.

Annual Report of the Committee on Names of Fishes

As we reported a year ago, the Committee is engaged in the preparation of a revision (Third Edition) of "A List of Common and Scientific Names of Fishes from the United States and Canada." We hope to complete copy by September, 1969, with publication scheduled to coincide with the Centennial Celebration of the American Fisheries Society a year later.

Five members of the Committee devoted three concentrated days to the work of revision last June. Much progress was made and a substantial fraction of the detailed problems were disposed of. It now becomes apparent that there will be many more additions and changes, especially in scientific names, than had previously been anticipated. Many of these changes will pose questions to users of the new list: What became of species A? Why does species B now show occurrence in both oceans instead of one? Species C did not appear in the 1960 edition—what reference dictates its addition? Why is species D assigned to a genus different from that given in 1960? To elucidate changes the Committee proposes incorporation in the new edition of an appendix providing documentation. Each entry of the main list which differs from the 1960 edition will be marked by an asterisk; a brief explanation or literature reference in the appendix will be keyed to the proper page and species entry of the list.

Many thoughtful and helpful communications from concerned users of the list have facilitated the work of revision; to the responsible parties we are much indebted. One suggestion recommends addition of a second list of extralimital species, perhaps as an appendix. This list, as proposed, could be flexible and would include such species not appearing on the main list as were deemed by the Committee to merit inclusion. Suggested examples include frequently displayed fishes of public aquaria, common home aquarium fishes, offshore or prominent foreign game fishes, exotic commercial or bait fishes sought or used by North American commercial fishermen, non-native fishes used in biological research as experimental animals, and foreign fishes which catch the popular fancy or interest and commonly appear in news dispatches. We welcome advice as to the desirability of activating this proposal.

We have received numerous suggestions for changes in common names on the list. These have been weighed on the premise that continuity assures the strongest support to the desired objectives of uniformity and stability in names. Thus, relatively few emendations have been accepted except for little-known, mostly smaller fishes. Two especially significant cases merit special mention; these involve the sockeye salmon (*Oncorhynchus nerka*) and the Greenland halibut (*Reinhardtius hippoglossoides*).

In the first edition of the names list (1948) *Oncorhynchus nerka* was called red salmon; in the second edition (1960) it appeared as sockeye salmon, with a footnote to indicate that lacustrine stocks are known as kokanee. The Committee has received two recent requests to return from sockeye to red salmon in the third edition, or to recognize these names as of equal status. In 1952 the Committee undertook a survey of names applied to the several species of Pacific salmon and solicited recommendations from many fishery workers, chiefly those with much firsthand experience or association. The replies were circulated through the Committee, which then voted in substantial agreement with the prevailing views of those workers. The results (1953, Trans. Am. Fish. Soc., 82, p. 327) favored sockeye salmon over red salmon (vote of 7–0). Since then, and especially after appearance of the Names List of 1960, casual inspection of the literature indicates a progressive gain in usage of the name sockeye salmon. No new evidence is contained in the new requests. After reconsideration the Committee concurs unanimously in recommending the retention of sockeye salmon for *Oncorhynchus nerka*.

The Committee on Names of Fishes has been asked to reconsider the common name Greenland halibut for *Reinhartius hippoglossoides* (Walbaum). This name is currently recommended in the AFS Special Publication No. 2 (1960). Some recommendations to the Committee favor substitution of the name northern flounder but all requests for change call for elimination of the "halibut" portion of the name.

The chief reason expressed for requesting a change of the current name is that *R. hippoglossoides* presents a marketing problem since, as expressed by one proponent, it ". . . . is being confused by the consumer in the market place with the true halibut of the Atlantic, *hippoglossus hippoglossus*, and of the Pacific, *Hippoglossus stenolepis*."

Some correspondents have indicated that the name Greenland halibut violates the Committee's Principle 16 (op. cit., p. 3), that reads as follows:

> "*Geographic distribution provides suitable adjectival modifiers.*—Poorly descriptive or misleading geographic characterizations (e.g., Kentucky bass for a wide-ranging species) should be corrected unless they are too deeply entrenched in current usage. In the interest of brevity it is usually possible to delete words such as lake, river, or ocean in the names of species (e.g., Colorado squawfish, not Colorado River squawfish)."

It is the opinion of the Committee that the name Greenland halibut is, indeed, deeply entrenched in the literature. This common name has been in existence at least since 1881 and is the name used abundantly in a wide variety of regional and international publications on fishes.

Among the International Fishery Commissions the name Greenland halibut has been accepted by ICNAF (International Commission North Atlantic Fisheries), ICES (International Commission for the Exploration of the Sea), INPFC (International North Pacific Fishery Commission), and the FAO (Food and Agriculture Organization) and is regularly used in their statistical bulletins and other publications. It is highly unlikely that any change in name would be acceptable to these organizations, especially for such a substitute as northern flounder. Not only is the name Greenland halibut accepted throughout the English-speaking world but the word "halibut" forms a part of the common name in a variety of European languages (French, fletan noir; German, schwarzer heilbutt; and Russian, paltus). The Committee on Names of Fishes did not coin the name

Greenland halibut; it accepted a name that had been in existence for 80 years, one that was widely used and well established.

On page 1 of the 1960 List of Common and Scientific Names . . ., the aims of the Committee are outlined as follows: "The Committee aims at the development of a body of common names that reflect broad current usage, the creation of a richer, more meaningful and colorful vernacular nomenclature, *and the promotion of mechanisms that will add to stability and the universality of names applied to American fishes.*"

Thus, the name Greenland halibut is widely, if not universally, accepted, and is obviously stable since it has endured for so many years.

Most of our English common names have come down to us from original British usage. A single word was commonly assigned to a species: salmon, trout, bass, perch, flounder, halibut, etc. (op. cit., p. 3, principle 13). As British peoples spread throughout the world they took these uninomials with them and applied them, usually with a modifier, to the vast number of fishes in other areas. Objectors to the use of the name Greenland halibut for *Reinhardtius hippoglossoides* have proposed that we rename that species, among other suggestions, as northern flounder or Newfoundland turbot. Adoption of one of these recommended changes would involve misuse of flounder or turbot precisely as we are charged with misusing halibut. The simple name halibut was originally applied by the English to *Hippoglossus hippoglossus* and, from the standpoint of priority, applies only to that species. The two most closely related species, *H. stenolepis* and *R. hippoglossoides*, have long been known with modifiers as Pacific halibut and Greenland halibut, respectively. To avoid possible confusion the Committee on Names of Fishes also utilizes a modifier, Atlantic, for *H. hippoglossus*. Although perhaps irrelevant here, it is of interest that Russian ichthyologists currently regard *H. hippoglossus* and *H. stenolepis* as subspecies of a single species.

Thus, it is our view that the term halibut is to be applied broadly to a number of species, just as the names salmon and bass are used. If it is contended that halibut can be properly assigned to no species other than *Hippoglossus hippoglossus*, then it follows that salmon should be restricted to *Salmo salar*. The analogy could be extended to other names with even greater disruption to established nomenclature.

In considering change from Greenland halibut, for whatever reason, cognizance must be taken of other names already in use. Turbot, for example, is almost universally used by Canadian fishermen, but as an alternative name it is unacceptable since it is pre-empted in both the Atlantic and the Pacific by other flatfishes. Blue halibut, lesser halibut, black halibut, mock halibut, and bastard halibut, are also used in English and other European languages and these probably would not be acceptable to those requesting a name change. The three last named would be objectionable from a marketing standpoint. To substitute a name such as northern flounder for Greenland halibut would constitute an abrogation of the very principles the Committee seeks to establish. The established, distinctive name of a valuable food fish would be abandoned with an unfamiliar and undistinguished replacement. The index to the names list now carries 50 entries for modifiers of the one word flounder, and many of the species are of northern distribution.

Differences exist in the inherent qualities of the flesh among the kinds of halibuts, as among other groups of related species. Also, variations in size of stocks, availability, and market demand inevitably create price differentials among species. The Committee does not believe that these factors warrant a change in nomenclature. If such considerations were accepted as a basis for changes in established names of species attainment of the constitutional directive "of achieving uniformity and avoiding confusion of nomenclature" would be vitiated.

In view of the foregoing, the Committee affirms the continued use of Greenland halibut for *Reinhardtius hippoglossoides* (Walbaum). If properly and accurately labeled, Atlantic halibut, Greenland halibut, and Pacific halibut should be easily distinguishable to the consumer.

Respectfully submitted: Reeve M. Bailey, Chr.; Earl S. Herald; Ernest A. Lachner; C. C. Lindsey; C. Richard Robins; Phil M. Roedel; and W. B. Scott.

The Annual Report of the Committee on Names of Fishes was:

Approved by the Executive Committee, American Fisheries Society, September 8, 1968.

Approved by the American Fisheries Society at its 98th Annual Meeting, Tucson, Arizona, on September 9, 1968.

REPORT BY THE EDISON ELECTRIC INSTITUTE

WATER TEMPERATURES AND AQUATIC LIFE

Prepared for

Edison Electric Institute Research Project No. 49

by

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We wish to acknowledge the many thoughtful contributions of the Task Force which consists of:

W. J. Robinson-- Chairman
M. C. Abrahm
M. A. Giles
H. M. Hammond
R. M. Homan
E. A. Lodge
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A. C. Thies

John C. Geyer
Charles E. Renn
John E. Edinger

Baltimore, Md., September 24, 1964

Foreword

This manual has been prepared as a quick reference and guide for engineers, managers, administrators, and others responsible for maintaining favorable water quality as part of industrial operations. It is specifically designed to examine effects of changes in water temperature upon fish life and upon small bottom living organisms that are important in the food economy of fish.

To make the manual generally useful to engineers who face the dilemma of evaluating the effects of temperature changes, the pertinent technical papers that have been reviewed have been arranged in a special way; separate sections have been developed to describe conditions that may apply with each 5° F. temperature increment. This is a convenient arrangement, but it introduces considerable repetition, some breaking apart of ideas, and a degree of awkwardness. Nevertheless, organization of the literature in this fashion will be a special convenience in the first searches for understanding.

Temperature variations affect fish life in a number of ways. Cataloging and describing all of the conditions associated with temperature changes is impossible. Rather than attempt this, the author has arbitrarily divided the abstracted information into seven categories and has applied this organization to each of the temperature groupings; these appear as marginal headings.

1. Effects of Exposure. This section includes information on the time-tolerance to changed temperatures as well as data on normal reactions to natural temperatures common to the climate and season.
2. Compound Stress Effects. This describes changes produced by temperature in conjunction with other limiting conditions, such as food supply, dissolved oxygen, and chemical pollutants.
3. Effects on Feeding and Growth.
4. Effects on Reproduction and Development.
5. Effects on Movement and Activity.
6. Adjustment to Temperature. This section includes references to sharply altered temperatures and the mechanisms by which fish admust themselves to the change.
7. Environmental conditions. This reviews chemical and physical changes produced by temperature and related biological alterations in the aquatic system.

While the author has tried conscientiously to produce a useful, unbiased organization of the published technical literature, he is keenly aware of many shortcomings in his efforts. The papers reviewed do not represent the complete record; many valuable observations are parts of restricted, unavailable special reports. Much pertinent work is in progress. Most difficult is to separate out useful information from experimental work that was designed for other primary purposes.

A certain staccato presentation could not be avoided. The requirement that suitable biological terms be used to describe biological materials makes lumpy going for non-biologists. It was felt desirable to address fish by their scientific names as well as by vaguer and frequently confusing common terms. For identification the usages recommended by The American Fisheries Society, "A List of Common and Scientific Names of Fishes from the United States and Canada, 2nd Edition, 1960" have been applied throughout.

All temperature records have been converted to ^{o}F. Since ^{o}C. is the more commonly used in the biological literature, the conversion produces the unintended effect of extreme precision--degree readings have been given to the nearest 0.1^{o}F.

This manual is a guide to the literature. The cited papers should be examined for critical purposes. It is to be noted that the studies have been developed by many kinds of investigators; by physiologists, by fisheries management biologists, by icthyologists, zoologists, ecologists, toxicologists, and workers in many disciplines. The journals in which the papers appear cover a wide range of technical interests, and it is highly unlikely that even a quarter of them will be found in a single technical library. The titles of the journals are sufficiently descriptive to direct anyone concerned with a source search. At the moment, however, there is no central repository of pertinent material on effects of heat upon aquatic life.

Many people have aided in the preparation of this manual, but special acknowledgement must be given Miss Barbara Hofheinz. Her acuity as a library assistant, her willingness to undertake major drudgery, and her cheerful participation made her indispensable.

Without the constant encouragement and enthusiastic aid provided by Dr. Charles E. Renn, the work would never have been completed. He is, in fact, a coauthor, but is not to be embarrassed by any weakness in the text.

Charles B. Wurtz

August, 1964

Effects of Changing Temperatures on Aquatic Animals--General

Fish and smaller, bottom-living, aquatic animals exist at or near water temperature. Unlike warm blooded animals, they cannot maintain fixed body temperatures when that of the external medium varies widely. Many adjustments are made by aquatic animals to meet changing temperatures, but the most prominent are altered activity and energy consumption.[1]

Generally, biological activity increases and the rates of biological processes rise with rising temperatures. The range and type of response varies among animal species, age, season of the year, previous experience and acclimation, and from individual to individual depending upon genetic make-up and physiological condition.

The most commonly noted effect of elevated water temperature is the increase in respiratory activity, of oxygen uptake and of carbon dioxide discharge between fish and the water medium. As water temperatures rise, the dissolved oxygen content of water normally declines. In extreme cases the oxygen concentration is insufficient to meet the higher demands of fish at elevated temperatures. Some fish and small animals are nearly independent of the oxygen concentration itself over wide ranges of dissolved oxygen concentrations; others respond or adjust themselves to the available oxygen supply.[2] Fish and small bottom-living animals are essentially fuel-consuming, energy-liberating machines, that store, convert, and free chemical energy. Rates of these processes are temperature conditioned, however, heat in water is not a source of energy.

1. Rao (1962)
2. Allee, Emerson, Park, Park, and Schmidt (1949)

A study of the dependence of respiratory rates of carp (Cyprinus carpio) on water temperature has been made.[1] The relationship between temperature and the oxygen content of the blood of largemouth bass (Micropterus salmoides) reflects the detail of internal adaptation involved.[2] Interestingly, it was found that the concentration of oxygen in arterial blood is more closely related to water temperature than to the oxygen content of the water itself. At high body temperatures the lactic acid level rises considerably, and increased lactic acid improves the combining power of haemoglobin with oxygen. Thus the largemouth bass is able to occupy certain habitats through physiological lability rather than through direct adaptation. The authors believe that the physiological responses of an organism above and below some optimum temperature ranges are stress responses. These latter reflect the degree of lability or of adaptation in the physiological process. It has been observed, and repeatedly demonstrated, that many aquatic organisms are able to acclimate to higher temperatures in relatively short times--a day or less--and that they lose this acclimation slowly.

Some apparently temperature determined responses are in reality intrinsic seasonal rhythms--as in the standard metabolism of the Pacific killifish (Fundulus parvipinnis).[3] This operates independently of the temperatures at which the fish are kept.

Food consumption and activity increase (within a restricted range) with rising temperature. The largemouth bass (Micropterus

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1. Meuwis and Heuts (1957)
2. Denyes and Joseph (1956)
3. Wells (1935)

salmoides) feeds more, and cruises more rapidly, as temperatures rise to 71.6°F. The optimum range observed fell between 71.6°F and 84.2°F.[1] Maximum activity was noted at 77°F.

Some fish are peculiarly adapted to very low temperatures--notably the Antartic species Trematomus bernacchii. Studies of this cold water, benthic (bottom living) fish which normally lives year round at temperatures between 28.6° F and 28.8° F, show that oxygen uptake rates (a measure of metabolism) increase up to 32°F.[2] Above this temperature the rate of oxygen uptake decreased. The species is extremely stenothermal--that is, it can function only over a short temperature range, and at low temperatures.

The practical aspect of the relationship between temperature and metabolic rate is expressed in the fish culturist's maxim: Feed heavy on a rise in temperature.[3] Fish commonly show a temporary exaggerated metabolic rate with a rise in temperature. This rate drops in about one day to the standard rate of the species at the new, higher temperature.

Several studies have demonstrated the presence of highly sensitive thermal receptors in the skin of fish, indicating perception of temperature changes as small as 0.09°F.[4,5] Practically, such slight differences appear to be ignored by the fish.

A number of measurements have been made of the internal body temperatures of fish.[6] The bowfin (Amia calva), carp (Cyprinus carpio), white sucker (Catostomus commersoni), channel cat (Ictalurus punctatus), black bullhead (Ictalurus melas), black crappie (Pomoxis

1. Johnson and Charlton (1960)
2. Wohlschlag (1960)
3. Anon (1956)
4. Bardach and Bjorklund (1957)
5. Sullivan (1954)
6. Clausen (1934)

nigromaculatus), white crappie (Pomoxis annularis), blue gill sunfish (Lepomis macrochirus), yellow perch (Perca flavescens), and warmouth (Chaenobryttus gulosus) have been examined. Temperature differences between the fish and the water in which it lived did not exceed 0.144°F. Simple muscular activity did not raise body temperature appreciably, but the body temperature rose with certain stimulations, even when no muscular action was evident. Apparently, increasing body temperature is a result of nervous stimulation. The body temperature of bowfin and white crappie rose as the water temperature rose, following closely. But at 68.7°F for the bowfin, and 65.5°F for the white crappie, there was an appreciable lag. Additional records of fish body temperatures and water temperatures reflect ranges in which lag appears.[1]

Aquatic invertebrates respond to rising temperatures and show temperature acclimation. The activity-temperature curves for mosquito larvae (Anopheles plumbeus and A. maculipennis) are much like those of the brook trout (Salvelinus fontinalis).[2] Respiration in two salt water pelecypods (Mytilus edulis and Brachidontes demissus plicatulus) varies with size and water temperature; pumping rates in amother pelecypod, Mytilus californianus, varied with geographic distribution[3]--cold acclimated M. californianus pumped at higher rates than warm-water specimens.[4] Populations separated by ten degrees of latitude had the same pumping rates as populations separated by temperatures of 3.6°F. The combination of genetic differences within local races may be a factor.

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1. Trembley (1960b)
2. Ivanova (1962)
3. Read (1962)
4. Rao (1953b)

Dragonfly nymphs (Aeschna) show an initial response of increased activity when introduced into warmer water, as well as an initial decrease in activity in colder water.[1] In a few days, however, they dropped back to levels close to their original metabolic rate.

No attempt will be made to produce a general theory of the mechanism of heat killing; there are a number of mechanisms, and these have been treated extensively by a number of physiologists.[2,3,4,5,6]

The most practical observation is that the lethal temperature limit is an individual and variable property.[7] The lethal temperature depends upon many factors, the diet of the test animals, activity, weather, season, osmotic stress, age, general health and many other conditions. It becomes difficult to describe these in a useful fashion.

The effects of sudden, sharp rises of temperature are especially difficult to assess, yet sudden change is common in many aquatic environments. The author[8] subjected mixed populations of micro-organisms to thermal shocks of 25°F temperature rise-- two week old populations developed at 70°F were raised to 95°F through a ten second period. No immediate kill was observed, but persistent exposure to 95°F over 24 hours brought about changes in the composition of mixed populations.

Adult striped bass (Roccus saxatilis) were transferred from fresh water to salt water with temperature increases of as much as 31°F (45°F to 76°F) without loss.[9] Rainbow trout (Salmo gairdneri)

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1. Sayle (1928)
2. Heilbrunn (1948)
3. Belchradek (1930)
4. Bullock (1955)
5. Prosser (1955)
6. Rao (1962)
7. Fry (1957)
8. Previously unpublished
9. Tagatz (1961)

failed to withstand the shock of 20°F rises after acclimation at 54°F, but survived the shock of 15°F rise from an acclimation temperature of 51°F.[1] Another study demonstrated that the brook trout (Salvelinus fontinalus) withstood temperature shocks as high as 36.8°F (37.4° to 74.2°F).[2]

There is an interesting record of shock from rising temperature by burning weeds along a channel.[3] Water temperatures rose 16.9°F (from 53.6°F to 70.5°F) in about five minutes. Juvenile chinook salmon (Oncorhynchus tshawytscha) in live cars survived, although they showed marked distress with increased temperatures and rising hydroxyl ion concentration from the ash leachings. (The water rose from pH 7.8 to pH 11.3--well within the killing range.)

Aquatic organisms in the condenser water stream are subjected to temperature shock. A limited number of studies have been made of the effects of such rapid rises in temperatures.[4,5] In a typical two-pass condenser there is a rise of about 7°F in three seconds in the header box, a short pause, then a further rise of 6° or 7°F in the second pass. The organisms in the water are also subjected to pressure changes--about four to one--and turbulent velocities of 40 ft. per second prevail. In intake collections 35 fresh water species and 62 marine species were found. These were found alive and with no evident damage in the outfall. Among the fresh water species were flatworms, nematode worms, rotifers, sludge worms, entomacracan crustaceans, a lymnaeid snail, black fly larvae and midge larvae.

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1. Threinen (1958)
2. Fry (1951)
3. Cushing and Olson (1963)
4. Markowski (1959)
5. Markowski (1960)

Many biologists have examined the effect of temperature on the activity of various toxicants to fish.[1, 2, 3, 4, 5, 6] This manual makes no attempt to cover this relationship, except to observe that increased temperature generally increases the toxicity of such substances.

Without doubt the most serious limitations to the interpretations that may be made from the studies cited in this manual rise from the fact that uniform conditions of study, observation, and reporting were not possible. The various projects were carried out for various purposes, and the investigators applied techniques and measurements that were most economical for their needs. In many of the references cited temperature was a secondary consideration.

The terms commonly used to describe temperature tolerance or lethality are confusing. For example, the term maximum lethal temperature is sometimes applied to mean the maximum tolerable temperature--the highest temperature at which all test animals survive. This is a useful measurement, but it is less suited to comparative tests of lethal conditions than a system in which some fixed fraction of the test population is killed within a fixed time limit--as the 24-hr./50% lethal limit, or the 48-hr./50% or 90% mortality.

A final limitation of laboratory lethality tests--which are of great value in averting catastrophic kills--is the fact that they rarely provide guidance to prolonged survival, good health, and a favorable balance of organisms in the practical environment.

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1. Cairns and Scheier (1959)
2. Cairns and Scheier (1962)
3. Clemens and Sneed (1958)
4. Lloyd and Herbert (1962)
5. Wurtz (1962)
6. Wurtz and Bridges (1961)

Effects of Temperature Changes on Mixed Populations

A healthy aquatic environment supports many kinds of organisms. Fish, and organisms that support the fish population, are studied most extensively because of their economical and recreational values. The effects of alteration of one or more important environmental factors will be shown in the less obvious, non-economic, little observed complex of living things.

The population complex of surface waters varies with seasonal changes in water quality--with light, temperature, turbidity, nutrients, currents, mixing etc. Many species have short life cycles so that they increase or decrease rapidly to take advantage of favorable changes or to survive unfavorable competition. Because of the rapid shifts in mixed populations, many stream biologists prefer to use them as indicators of water quality.

Usually clean, high-quality waters are distinguished by a diversity of species. In 1948, from 55 samples collected at 44 places in the Conestoga Creek (Pennsylvania) drainage basin the Academy of Natural Sciences of Philadelphia[1] identified 1,003 different species. Not all of the species collected could be identified, but the total number of different living forms taken in the survey probably amounted to more than 1200 species. Only about one tenth of this total would be found living together in the same place, but it is these smaller, local populations that reflect the influence of alterations in the environment.

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1. Anon. (1949)

A classic demonstration of the effects of increasing water temperatures upon the shift in species of an insect population is given by Walshe[1]. The thermal index (22-hr LD_{50})of seven species of midge larvae reflect the probable sequence of their preferred temperatures. These seven species, and their thermal indices were: Tanytarsus brunnipes, 84.2°F.; Prodiamesa olivacea, 86°F.; Anatopynia nebulosa, 86.9°F.; Chironomus riparius, 94.1°F.; C. albimanus, 95°F.; C. longistylus, 95.9°F.; and Anatopynia varia, 101.8°F. If rising temperatures took place with loss of the less tolerant species and replacement with the tolerant survivors, who would know, and who cares? However, it could be a change of considerable consequence; the small-mouth bass (Micropterus dolomieu) and the midge Tanytarsus brunnipes, would probably be lost from the population at the same time in the interval of rising temperature, but only the small-mouth bass would be missed.

A shift in the population structure of the bottom fauna population of Lake Erie has been observed[2]. This change was apparently the result of a slightly increased temperature in association with chemical changes. The mean annual temperature is approximately 2°F. warmer than in the decade 1918 to 1928, when the average annual temperature was 50.9°F. However, the greatest increase in the mean annual temperature was between 1925 and 1930, and there has been no significant change since. Prior to 1918-1928, the bottom fauna was dominated by mayfly nymphs (Hexagenia), but the dominant forms now are midge larvae and oligochaete worms.

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1. Walshe (1948)
2. Beeton (1960)

The blue pike (Stizostedion vitreum glaucum) and the cisco (Coregonus artedi) formerly dominated the commercial fish catch, but these have been replaced by other species.

The record of the most pronounced increase of water temperatures by manufacturing activities is, apparently, that of the Mahoning River in Ohio. Ohio steel mills were once reported[1] as using the water, over and over, twenty-four times, for cooling purposes. The maximum water temperature above the mills was 81°F., but after repeated use it rose to above 140°F. Obviously this stream would have a much reduced fauna. In September, 1960, only eight macro-invertebrate species were living in the river where it crossed the Ohio-Pennsylvania border[2]. Hot water was not the only pollutant at the time, however, and hot water discharges were being controlled by 1960.

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1. Carhart (1957)
2. Wurtz and Dolan (previously unpublished)

Biological Phenomena Reported Occurring at Temperatures below 50°F.

Most aquatic animals live some, or all, of their life at temperatures well below 50°F. This is normal, and these animals carry on their life processes without discomfort. However, even as there is an upper lethal temperature for living forms, so, too, is there a lower lethal temperature. It is apparent that a freezing temperature (32°F.) must be a critical point for many animals.

Effects of Exposure

High and low lethal limits were determined[1] for the young of five species of Pacific salmon. These fish were the chinook salmon (*Oncorhynchus tshawytscha*), pink salmon (*O. gorbuscha*), sockeye salmon (*O. nerka*), chum salmon (*O. keta*) and coho salmon (*O. kisutch*). None of these could withstand temperatures exceeding 77.9°F. when exposed for one week. When acclimated to 68°F. none of the salmon could withstand temperatures below 39.2°F. When acclimated to 41°F. coho and sockeye salmon could not tolerate four days of exposure to 32°F. The upper lethal temperatures found were 75.2° to 76.1°F. for the young of these five species.

Pitkow[2] lowered water temperatures to 36.6°F. in experimenting with guppies (*Lebistes reticulatus*). In lowering temperatures to this level from an acclimation temperature of 73.4°F. during a 15-minute interval 13 of 16 fish died. In association with other experiments the author found males less cold-tolerant than females,

1. Brett (1952)
2. Pitkow (1960)

and the young less cold-tolerant than adults. Tolerance to lack of oxygen was found to be inversely proportional to acclimation temperature.

Seasonal adjustment to environmental conditions by acclimation has long been known. It has been demonstrated experimentally[1] that goldfish (Carassius auratus) acclimated to short-day (winter) light conditions were more resistant to cold than other fish acclimated to long-day (summer) light conditions. Short-day fish had 25% kill at 34.2°F. in 198 minutes, while the long-day fish had a similar kill in 102 minutes. All these fish had been acclimated to water temperatures of 64.4° to 68°F. for 40 and 50 days before the experiment.

Osmoregulatory controls in goldfish (Carassius auratus) have been studied[2] at low temperatures. The fish, acclimated to 68° to 71.6°F., suffered cold death when abruptly transferred to water of 36.5° to 38.3°F. There was some loss of osmoregulatory control at the low temperatures, but this was not considered to be severe enough to have caused the cold death.

Carp (Cyprinus carpio) need a temperature of 26.6°F. (in the absence of ice) before becoming motionless from cold[3]. Mosquito fish (Gambusia sp.) become motionless at 32.4° to 32.5°F. and respiration stops after 45 to 65 minutes.

Compound Stress Effects

In studying temperature and photoperiod in rainbow trout (Salmo gairdneri), fish were acclimated[4] for 43 days to four conditions of

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1. Hoar (1956)
2. Houston (1962)
3. Deelder (1958)
4. Evans, Purdie and Hickman (1962)

temperature and light. These were 8 and 16 hours of light at 46.4° and 60.8°F. Oxygen consumption of the fish as well as of several tissues was measured. Brain tissue showed complete metabolic compensation to temperature and the authors suggested that this would maintain nervous co-ordination and motor control at optimal levels. This would permit a large degree of temperature independence of locomotor activity. Photoperiod did not significantly affect total metabolic rates.

<u>Effects on Feeding and Growth</u>

Trout actively fed on numerous occassions when the water temperature was 32° to 33°F[1]. These were field observations, and the fish were living under natural conditions. Bottom organisms, utilized as food by the trout, were abundant. The trout included brook trout (*Salvelinus fontinalis*), rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*). The stream (Sagehen Creek, Cal.) was a cold-water stream with mean maximum daily water temperature during August of 65.2°F.

Mekhanik[2] studied growth and metabolism in young Ladogian salmon (g. sp.?) and rainbow trout (*Salmo gairdneri*). The young of the trout showed slower growth at 57.2° to 64.4°F. than did the young salmon at 44.6° to 46.4°F. At 60 days the optimal temperature for growth of the salmon was 59°F.

Activity of the digestive enzymes of a fish at 32.9°F. have been experimentally demonstrated[3]. Protein tubes were passed through the stomach of the Siberian dace (g. sp.?)at temperatures ranging

1. Needham (1959)
2. Mekhanik (1955)
3. Pegel (1959)

from 32.9° to 75°F. The motor function and enzymatic action of the digestive system functioned throughout this range.

The largemouth bass (Micropterus salmoides) does not feed at 41°F. where a very low scope for activity was observed[1]. In another study[2] on this species, a more rapid rate of increase in the rate of digestion between 41° and 50°F. than at higher temperatures was found. These fish were force-fed. The data show that seasonal changes in intensity of digestion would be expected. In winter the rate of emptying the stomach would be five to six times slower than in the summer. The presence of food would be more important to the bass in warm water than in cold water.

Trout were taken on bait when the water temperature was 32°F.[3] These fish were active in the freezing water (Convict Creek, Cal.) and fed regularly throughout the winter. The brown trout (Salmo trutta)and rainbow trout (S. gairdneri) were the principal species in the region studied, but an occasional brook trout (Salvelinus fontinalis) was taken.

Effects on Reproduction and Development

Not all aquatic animals can withstand temperatures near freezing, and especially at certain sensitive stages in their life history. Twinning occurred in the eggs of three-spine stickleback (Gasterosteus aculeatus) when these were subjected to freezing temperatures for one-half to three hours[4]. The lower lethal temperature for herring larvae (a salt-water species) was found[5] to range from 32.7° to 35°F. A temperature of 36.5°F.

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1. Johnson and Charlton (1960)
2. Molnar and Istvan (1962)
3. Maciolek and Needham (1951)
4. Swarup (1959)
5. Blaxter (1960)

caused deformation in the embryo of brown (Salmo trutta) and rainbow trout (S. gairdneri)[1]. It is apparent that the embryos of these latter are more cold-sensitive than are the adults.

The lower threshold temperature for normal development in the chinook salmon (Oncorhynchus tshawytscha) was found[2] to be 42.5°F.

In further studies at Sagehen Creek, the spawing period for brook trout (Salvelinus fontinalis) was found[3] to occur between 37° and 44°F. In trout waters this seven-degree range would, of course, be critical.

In the field[4] chinook salmon (Oncorhynchus tshawytscha) began spawning at 42°F. (Toutle River, Wash.) and 43°F. (Willamette River, Ore.). Spawning continued to 58°F. in the first river, and 64.5°F. in the latter. In the Columbia River in southwestern Washington spawning occurred at 50° to 62°F.

The walleye (Stizostedion vitreum) shows maximum spawning activity in water at 45° to 50°F.[5]

Oviposition in the pond snail (Physa gyrina) begins when temperatures reach 50°F.[6] These snails, when kept anaerobically from 32° to 50°F., live three times as long as they do when kept at 68°F.

Effects on Movement and Activity

Studies on the activity of brook trout (Salvelinus fontinalis) before and after brain lesions were made[7]. The frequency of spontaneous movements was determined at several constant temperatures. The frequency of movement was low at low temperatures. Minimum activity occurred at 64.4°

1. Orska (1956)
2. Combs and Burrows (1957)
3. Needham (1961)
4. Olson and Foster (1955)
5. Rawson (1956)
6. DeWitt (1955)
7. Fisher and Sullivan (1958)

to 66.2°F. There was a high frequency at 48.2°F., and a second peak of high frequency at a prelethal temperature of 75.2°F. Destruction of the dorsal part of the cerebellum caused the disappearance of the activity peak at 48.2°F. (These studies were done in the spring before acclimation to summer temperatures had taken place.)

Adjustment to Temperature — Little difference in preferred temperature was found[1] for the young of five species of salmon when the fish were put into water with a temperature gradient. Regardless of acclimation temperature, the thermal range of 53.6° to 57.2° was the range most commonly occupied by all five species. The five species studied were: chinook salmon (Oncorhyncus tshawytscha), pink salmon (O. gorbuscha), sockeye salmon (O. nerka), chum salmon (O. keta) and coho salmon (O. kisutch).

A very extensive study on preferred temperature of fish and their midsummer distribution in relation to temperature was published by Ferguson[2]. This study included numerous MS data from other works. Although differences were found between laboratory results and observed field conditions, the author pointed out that these differences could be attributed to the fact that young fish were used in the laboratory while older fish were observed in the field. Among the fish studied in the laboratory none were found to have a final temperature preferendum below 50°F. However, species found in habitats with water temperatures below 50°F. during August (or other hot-weather period) included: an alewife (given as Pomolobus namaycush)

1. Brett (1952)
2. Ferguson (1958)

at 39.9° to 47.8°F., lake trout (*Salvelinus namaycush*) at 46.4° to 50°F., American smelt (*Osmerus mordax*) at 43.8° to 46.1°F., and cisco (*Leucichthys artedi*) at 41.9° to 44.9°F. as well as at 46.4° to 50°F. These four species are obviously cold-water species.

Temperature selection in brook trout (*Salvelinus fontinalis*) has been studied[1]. The fish were permitted to move through water ranging from 33.8° to 75.2°F. Two- to three-inch fish were used in a trough five feet long and 82 determinations were made. The fish represented five stocks and the study was continued over four winters. The selected November-to-January temperature was 46.4°F. The selected temperature during the other months was $53.6^{+\circ}$ F. The authors suggested that these selected temperatures were a seasonal response rather than a product of acclimation temperature.

In water that fluctuated from 39.2° to 53.2°F., in ice-covered ponds, water fleas (*Daphnia magna*) were not harmed[2]. It was concluded that *Daphnia* would survive through the winter if plenty of food was available and if the water temperatures did not fall below 39.2°F.

Environmental Conditions Teter[3] published on the bottom fauna of Lake Huron at sampling depths of 5.5 to 119 meters. Temperatures ranged from 39.6° to 44.8°F. in samples taken below 25 meters, and from 56.7° to 66.5°F. in shallower water. Somewhat over 20 species of macro-invertebrate organisms (not all were identified) were taken from the depths below 25 meters. These

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1. Sullivan and Fisher (1953)
2. Beliaev (1958)
3. Teter (1960)

animals included Hydra, turbellarian flatworms (2 species), nematode worms (2 species), Naidium sp., Limnodrilus claparedianus, an unidentified leech, Pisidium, Sphaerium, Valvata, two ostracods, Asellus sp., Pontoporeia affinis (the numerically dominant organism), Mysis relicta, and one or more species of the midge genera Clinotanypus, Calopsectra, Procladius, Spaniotoma, Polypedilum, as well as other, unidentified, midge larvae.

Biological Phenomena Reported Occuring in a Thermal Range of 50° to 55°F.

Compound Stress Effects

Some studies[1] on the mean lethal oxygen concentrations for several fish at different temperatures have been made. For brook trout (Salvelinus fontinalis) at 55°F. the mean lethal concentration was 1.59 ppm; for brown trout (Salmo trutta) at 49°F. it was 1.42 ppm; for rainbow trout (Salmo gairdneri) at 52°F. it was 1.05 ppm. The mean lethal dissolved oxygen concentration for smallmouth bass (Micropterus dolomieu) at 52.5°F. was 0.63 ppm.

Studies[2] at Oregon State College of the effect of low oxygen tension on coho salmon (Oncorhynchus kisutch) showed that young coho salmon within a temperature range of 53.6° to 75.2°F. could withstand dissolved oxygen levels below 3 ppm.

A study[3] of the physiological products of fish activity investigated several species of fish. These were: "Kamloops" trout (Salmo gairdneri), longnose sucker (Catostomus catastomus), carp (Cyprinus carpio), squaw fish (Ptychocheilus oregonense), largemouth bass (Micropterus salmoides) and black catfish (Ictalurus melas). It was found that following 15 minutes of forced exercise at 52.7°F. the haemoglobin level increased only in the largemouth bass, and the lactic acid increased significantly in all species.

The effect of temperature on biological rates has been presented[4]. In a study on the toxicity of certain insecticides to the goldfish (Carrassius auratus) and the guppy (Lebistes

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1. Burdick, Lipshuetz, Dean and Harris (1954)
2. Anon. (1954)
3. Black (1955)
4. Adlung (1957)

reticulatus), temperature was found to have little effect on the absolute lethal dose. However, the progress of the toxic action was depressed by lowered temperatures. The critical period, when damage done the fish was not reversible, was 25 times as long at 39.2°F. and 51.8°F. as at 66.2°F.

Effects on Reproduction and Development

Brook trout (Salvelinus fontinalis) and rainbow trout (Salmo gairdneri) eggs develop normally at about 55°F., while brown trout (Salmo trutta) and Atlantic salmon (Salmo salar) eggs develop normally at about 50°F.[1] After feeding starts all three trout do best at 55°F. The salmon seems to do best at 60° to 65°F.

In a study[2] on temperature as it relates to the incubation and survival of small mouth bass (Micropterus dolomieu) eggs, it was found that raising the temperature of the eggs from 53°F. to 77°F. caused no kill. Eggs developing at 65°F. were transferred to 50°F. through a 30-minute period. No ill effects were found. Mean incubation period at 55°F. was nearly ten days.

Adjustment to Temperature

Stocking trout in Glacier National Park met with little or no success in waters below 55°F.[3]

Environmental Conditions

Temperature preferenda from experimental work, and observed environmental temperatures, have been presented[4]. Among the salmonids with a preferred temperature in the 50° to 55°F. range are: pink salmon (Oncorhynchus

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1. Markus (1962)
2. Webster (1945)
3. Hazzard (1933)
4. Ferguson (1958)

gorbusha) and chinook salmon (O. tshawytscha) (53°F.), lake trout (*Salvelinus namaycush*)(53.6°F.), *Salvelinus* hybird (53.6°F.) and brown trout (*Salmo trutta*) (54.5° to 63.6°F.) The lake whitefish (*Coregonus clupeaformis*) had a preferred temperature of 54.8°F. Environmental temperatures observed (mid-summer) between 50° and 55°F. included the following species at the temperatures indicated: lake trout, 50° to 59.9°F., 51.8° to 52.7°F. and 52.9°F; brook trout (*Salvelinus fontinalis*) 53.6° to 68°F.; sockeye salmon (*Oncorhynchus nerka*), 51° to 75°F.; lake whitefish (*Coregonus* clupeaformis), 51.8° to 52.8°F.; and the burbot (*Lota lota maculosa*), 51.4° to 52.5°F.

As mentioned earlier[1], brook trout (*Salvelinus fontinalis*) selected a preferred temperature of 53.6°F. during non-winter months.

The bottom fauna and the fish of Nolichucky River in Tennessee have been reported upon[2,3]. Only three of the stations listed in the two reports were correlated. These three had recorded temperatures of 50°F. on November 10-11, 1958. The number of macro-invertebrate organisms ranged from 19 to 46 species, while the fish ranged from 16 to 23 species at these three stations.

A mean temperature for the first 10 meters of Wollaston Lake, Saskatchewan, has been recorded[4] as 54.6°F. The maximum bottom temperature was 42.4°F. The bottom fauna included oligochaetes, sphaeriid clams, amphipods and midge larvae. The fish fauna included lake whitefish (*Coregonus clupeaformis*),ciscoes (*Leucichthys*

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1. Sullivan and Fisher (1953)
2. Mullican, Sinclair, and Isom (1960)
3. Ward (undated)
4. Rawson (1960)

spp.), northern pike (Esox lucius), walleye (Stizostedion vitreum), white sucker (Catostomus commersoni), longnose sucker (Catostomus catostomus), burbot (Lota lota) and lake trout (Salvelinus namaycush).

Biological Phenomena Reported Occurring in a Thermal Range of 55° to 60°F.

Effects of Exposure The upper lethal temperature for lake trout (*Salvelinus namaycush*) is 74.3°F., while the temperature for maximum activity is 59° to 62.6°F.[1] The "ultimate lethal temperature of 23.5° C. is one of the lowest on record" (i.e. 74.3°F.). (This refers to fresh water salmonid fishes.) The authors indicated ultimate upper lethal temperatures to be 77.5°F. for the brook trout (*Salvelinus fontinalis*) and the brown trout (*Salmo trutta*); 74.8° to 77.2°F. for species of salmon (*Oncorhynchus*); and 80.6°F. for the Atlantic salmon (*Salmo salar*).

Dependence upon temperature on the frequency of respiratory movement in carp (*Cyprinus carpio*) was studied[2]. Fish size primarily determined the degree of dependence upon temperature. Small fish were only slightly dependent upon temperature. Small fish had a broad homeostatic zone of independence, but this disappeared as the fish increased in size. As this homeostatic zone was reduced the upper lethal temperature decreased. (This was a decrease from 100.4° to 102.2°F. in small fish to 95° to 96.8°F. in large fish.) The small fish were apparently homeostatic for temperature within the range of 60.8° to 95°F., and, according to the authors, to this range they are probably best adapted.

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1. Gibson and Fry (1954)
2. Meuwis and Heuts (1957)

Effects on Feeding and Growth Young rainbow trout (Salmo gairdneri) have faster growth rates at 57.2° to 64°F. than at lower temperatures[1]. A temperature of 59°F. was optimal for growth of the ladogian salmon (g. sp.?) at 60 days of age.

Baldwin[2] held individual brook trout (Salvelinus fontinalis) at six temperatures between 38.3° and 69.8°F. The trout consumed most food (minnows) and made their best growth at 55.4°F.

Effects on Reproduction and Development Using mortality as a criterion, the threshold temperatures for normal development of the eggs of chinook salmon (Oncorhynchus tshawytscha) were measured[3]. The eggs were held at constant temperatures ranging from 35° to 60°F. Mortalities resulting from temperatures ranging below 42.5°F. and above 57.5°F. were statistically significantly different. For constant temperature conditions the lower and upper threshold temperatures were established at 42.5° and 57.5°F. respectively.

Temperatures below 57.2°F. are lethal for the eggs and larvae of the orangethroat darter (Etheostoma spectabile)[4]. This held true for both a southern (Texas) race and a northern (Missouri-Arkansas) race of the species. In field collecting of the greenthroat darter (Etheostoma lepidum) recorded[5] water temperatures at collecting stations ranged from 44.6° to 95°F. However, most station water temperatures ranged from 57.2° to 75.2°F.

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1. Mekhanik (1955)
2. Baldwin (1956)
3. Combs and Burrows (1957)
4. Hubbs and Armstrong (1962)
5. Hubbs and Strawn (1957)

The effects of temperature on the embryological states of the sea lamprey (Petromyzon marinus) have been studied[1]. Eggs were reared at ten constant temperatures from 45° to 80°F. At temperatures below 60°F. or above 70°F. no viable, burrowing larvae were produced. The optimum temperature (65°F.) produced 78% survival to the burrowing stage.

Sexually mature smallmouth bass (Micropterus dolomieu) in the Columbia River moved from the river into sloughs for spawning[2]. These spawning areas were generally between 55° and 60°F. At the same time the main river channel was 45° to 50°F.

Yellow perch (Perca flavescens) spawned in Upper, Middle, and Lower Thompson Lakes (Montana) in May when the surface water temperature was 57°F.[3] Egg deposition occurred in the upper five feet of water.

Good production of carp (Cyprinus carpio) was obtained at 59°F.[4]

Adjustment to Temperature

The final temperature preferenda[5] for chum salmon (Oncorhynchus keta) and sockeye salmon (O. nerka) are 57.4°F. and 58.1°F. respectively. Among the trout, the temperature preferendum of the brook trout (Salvelinus fontinalis) was given as 57.2° to 60.8°F. and that of the rainbow trout (Salmo gairdneri) was given as 56.4°F. Observed mid-summer environmental temperatures falling, at least in part, in the 55° to 60°F. range, were given for seven species. American smelt (Osmerus mordax) was found at 55°F. Brook trout was found at

1. Piavis (1961)
2. Henderson and Foster
3. Echo (1955)
4. Meuwis and Heuts (1957)
5. Ferguson (1958)

57.5° to 68.5°F., while a Salvelinus hybrid was observed at 57.5°F. "Land-locked" salmon (Salmo salar sebago) was living at 56.4° to 61.1°F. The white sucker (Catostomus commersoni) was found at 57.3° to 64.9°F. Round whitefish (Prosopium cylindraceum) was observed at 57° to 63.5°F. The rock bass (Ambloplites rupestris) was living at 58.4° to 70.3°F.

Mantleman[1] studied the distribution of fish in experimental gradients. Each fish species was found to have a characteristic temperature zone where the species occurred most frequently. For young rainbow trout (Salmo gairdneri) this selected temperature zone ranged from 55.4° to 66.2°F. Independently of season these young fish tended to avoid temperatures above 69.8° to 71.6°F. and below 46.4° to 48.2°F. Mantleman considers the rainbow trout to be relatively stenothermic and thermophilic. Very young fish reacted most quickly to temperature. It is indicated that for rainbow trout the selected temperature is a stable characteristic for any long-established population. The species is considered to have high plasticity relative to temperature, which, in turn, permits the preservation of normal vigor under a changing temperature regime.

A final temperature preferendum for the rainbow trout (Salmo gairdneri) was found[2] at 55.4°F. Trout were acclimated to 41°, 50° , 59° and 68°F. The corresponding preferred temperatures were 60.8°, 59°, 55.4° and 51.8°F. No other fish has been reported with decreasing preferred temperatures correlated with increasing acclimation temperatures.

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1. Mantleman (1960)
2. Garside and Tait (1958)

A fresh-water snail (Viviparus malleatus) was found to be inactive below 58.5°F.[1] This snail was most active in a thermal range of 62.5° to 81.5°F.

Environmental Conditions — Rawson[2] reported on the bottom fauna and fish found in several lakes in Saskatchewan. In Athabaska, Cree and Reindeer lakes the mean temperature of the first 10 meters of water was 56.1°, 58.8° and 57.5°F. respectively. The corresponding maximum bottom temperatures were 40.6°, 50.1° and 43.7°F. Bottom organisms included oligochaetes, sphaeriid clams, amphipods and midge larvae. The fish found included lake whitefish (Coregonus clupeaformis), ciscoes (Leucichthys spp.), northern pike (Esox lucius), walleye (Stizostedion vitreum), white sucker (Castostomus commersoni), longnose sucker (Catostomus catastomus), burbot (Lota lota) and Lake trout (Salvelinus namaycush).

1. Hutchinson (1947)
2. Rawson (1960)

Biological Phenomena Reported Occurring in a Thermal Range of 60° to 65°F.

Compound Stress Effects

Rainbow trout (*Salmo gairdneri*), held[1] at 60.8°F. with eight hours of light daily tended to show a higher metabolic rate than others held at the same temperature but subjected to 16 hours of light daily.

Among the invertebrate animals, the relationship between temperature and respiratory rates in European scuds (*Gammarus* sp.) have been studied[2]. *Gammarus* from the Rhone River had a "slow rate" of respiration at 64.4°F., and the rate increased with higher temperatures.

Effects on Feeding and Growth

Young Atlantic salmon (*Salmo salar*) seem to grow best at 60°F.to 65°F.[3] This is a somewhat higher temperature than that (55°F.) at which trout do best.

Largemouth bass (*Micropterus salmoides*) fry were reared at seven constant temperatures ranging from 59° to 86°F.[4] At 59°F. the eggs hatch and the fry rise from the nest, but only a few feed. The minimum temperature at which the fry (from Texas) feed lies close to the spawning temperature of 60.7°F.

Effects on Reproduction and Development

Chinook salmon (*Oncorhynchus tschawytscha*) eggs could begin incubation at temperatures as high as 61°F. without significant losses[5]. The upper temperature levels for chinook salmon spawning falls above 60°F., but below 65°F.

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1. Evans, Purdie and Hickman (1962)
2. Wautier and Troiani (1960)
3. Markus (1962)
4. Strawn (1961)
5. Olson (1955)

American shad (Alosa sapidissima) start their spawning run in the St. Johns River, Florida, at 60°F.[1] The run continues until river temperatures reach 75°F. Since the shad enter the river when river temperatures are lower than ocean temperatures, and continue running even when river temperatures are higher than ocean temperatures, some factor other than temperature differential presumably stimulated the fish. The peak of the shad run enters the Hudson River (New York) when river temperatures are 45° to 57°F.

Gonadal development, as measured by egg diameter, in the brook trout (Salvelinus fontinalis) was found[2] to be the same at 60.8°F. as at 47.3°F. provided the fish are exposed to natural day lengths.

The opitmum temperature for development of sea lamprey (Petromyzon marinus) eggs is 65°F.[3]

Adjustment to Temperature

Minimum activity in the brook trout (Salvelinus fontinalis) occurs at 64.4° to 66.2°F. in the spring before acclimation to summer temperatures has taken place[4].

One year and two year old lake trout (Salvelinus namaycush) display maximum swimming speed in the region of 60.8°F.[5]

Environmental Conditions

Ferguson[6] reports brook trout (Salvelinus fontinalis) living in streams with a summer temperature of 60.2°F. The mottled sculpin (Cottus bairdi) was reported in streams with a summer temperature of 61.7°F. Ferguson also reported preferred temperatures of

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1. Walburg (1960)
2. Henderson (1963)
3. Piavis (1961)
4. Fisher and Sullivan (1958)
5. Gibson and Fry (1954)
6. Ferguson (1958)

62.6°F. for yellow perch (Perca flavscens) acclimated at 50°F. This was the work of McCracken and Starkman and conflicts with Ferguson's own data which demonstrated higher (but unspecified) preferred temperatures.

The thermal range to which carp are best adapted begins at 60.8°F. and extends to 95°F.[1]

In a series of lakes sutdied[2] in Saskatchewan, nine had a mean temperature in the first 10 meters of water ranging from 60.4° to 63.8°F. Maximum bottom temperatures ranged from 48.5° to 64.4°F. The bottom fauna included oligochaetes, sphaeriid clams, amphipods and midge larvae. Lake trout (Salvelinus namaycush) were found in only four of these lakes, but their absence was not correlated with the temperatures recorded. The longnose sucker (Catostomus catostomus) was present in eight of the nine lakes. All nine lakes had lake whitefish (Coregonus clupeaformis), ciscoes (Leucichthys spp.) northern pike (Esox lucius), walleye (Stizostedion vitreum), white sucker (Catostomus commersoni) and burbot (Lota lota).

1. Meuwis and Heuts (1957)
2. Rawson (1960)

Biological Phenomena Reported Occurring in a Thermal Range of 65° to 70°F.

Effects of Exposure

The alevins of salmon (presumably Salmo salar), "sea trout" (probably sea-run rainbow trout, Salmo gairdneri) and brown trout (Salmo trutta) could live for 16 days without ill effects at 68°F.[1] Higher temperatures caused some mortalities. Resistance of salmonid alevins with yolk sacs did not appear to change with age.

Extensive work on the body temperature of fresh-water fishes has been done.[2] In two cases, as the temperature of the water increased the fish temperature followed closely, but beyond a certain maximum water temperature there was a lag in the body temerpature. These two cases were the bowfin (Amia calva) and the white crappie (Pomoxis annularis). The maximum temperature, beyond which there was a lag in fish-body temperature, was 68.7°F. for the bowfin and 65.5°F. for the white crappie. The latter died while the temperature was above 65.5°F., but bowfin, with a body temperature below that of the water, continued to live up to 73.9°F., when the water was allowed to cool. At 68.7°F. the fish assumed the water temperature. Although in poor condition, the fish appeared normal after a few hours in cool water.

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1. Bishai (1960)
2. Clausen (1934)

Compound Stress Effects

The minimum oxygen pressure found[1] for one-year old lake trout (*Salvelinus namaycush*) was 40 mm Hg at 68°F. For two-year old fish the minimum oxygen pressure at 68°F. was 60 mm Hg.

Lethal oxygen concentrations for several fish were investigated[2]. At 70°F. the mean lethal concentration of oxygen for brook trout (*Salvelinus fontinalis*) was 2.54 ppm. At 69°F. the mean lethal concentration for brown trout (*Salmo trutta*) was 2.53 ppm.

Brook trout (*Salvelinus fontinalis*) frequent waters varying in mean summer temperature from 50.9° to 69.8°F.[3] The respiratory rate of these trout rose rapidly with temperature to a peak at about 66.2°F., after which it fell quite rapidly. The upper incipient lethal temperature was found at 77.5°F. The relation between standard metabolism and temperature was found to be similar to this character in other fish. The proportional rate of increase gradually drops with temperature increase, while the absolute rate increases with increasing temperatures.

Effects on Reproduction and Development

The eggs of the brown trout (*Salmo trutta*) and the rainbow trout (*Salmo gairdneri*), when subjected to 68°F. while in various stages of development, produced individuals with varied numbers of vertebrae and fin rays[4].

Optimum egg production for the greenthroat darter (*Etheostoma lepidum*) began at 68°F. and extended to 73.4°F.[5]

1. Gibson and Fry (1954)
2. Burdick, Lipschuetz, Dean and Harris (1954)
3. Graham (1949)
4. Orska (1956)
5. Hubbs and Strawn (1957)

Although Meuwis and Heuts[1] stated the carp (Cyprinus carpio) is adapted for a thermal range of 60.8° to 95°F., they referred to earlier work by Heuts wherein the best temperature for development was found to be between 68° and 77°F.

Adjustment to Temperature

Young rainbow trout (Salmo gairdneri) as a rule avoided temperatures exceeding 69.8° to 71.6°F.[2]

The young of Acipenser guldenstadti persicus preferred a temperature of 68.2°F. in the presence of abundant food, and a temperature of 66°F. during starvation[3]. Young Acipenser nudiventris had corresponding temperatures of 66.6°F. and 64°F. The temperatures selected by hybrids between these two sturgeon species were close to the preferred temperature of the mother fish.

Among the data presented by Ferguson[4] were preferred temperatures for the yellow perch (Perca flavescens). Among these were a mean temperature of 65.4°F. (mode, 63.5°F.) for fish acclimated to 46.4°F., and a mean temperature of 68.7°F. (mode, 69°F.) for fish acclimated to 50°F.

The optimum thermal range for guppies (Lebistes reticulatus) was observed to be 68° to 77°F.[5] Gravid females died at temperatures below 68°F.

Environmental Conditions

Good trout streams should have temperatures that do not exceed 68°F.[6] This would certainly be the case for brook trout (Salvelinus fontinalis) at least.

1. Meuwis and Heuts (1957)
2. Mantleman (1960)
3. Dzyan (1959)
4. Ferguson (1958)
5. Gibson (1954)
6. Tarzwell (1957)

Cold Stream Pond, Maine[1], is a large (3,628 acres) lake with thermal stratification in the summer. Surface water temperatures seldom exceed 70°F. while temperatures in the hypolimnion average about 51°F. Lake trout (Salvelinus namaycush) and 20 other species of fish are known to be present in the lake.

Accumulated field observations[2] in the 65° to 70°F. thermal range included yellow perch (Perca flavescens) living in waters with summer temperatures of 67.4°, 68.5°, 69.4°, and 69.8°F. The rock bass (Ambloplites rupestris) was resident in streams with summer temperatures of 69.2°F., and in lakes with summer temperatures ranging from 58 to 70.3°F. The sauger (Stizostedion canadense) lived at summer temperatures of 65.4° to 66.5°F., while the walleye (Stizostedion vitreum) was found at 69.1° to 73°F. The smallmouth bass (Micropterus dolomieu) was found at summer water temperatures of 67.5° to 70.5°F. Each of the waters where these maximum or near-maximum annual temperatures were found is identified.

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1. DeRoche and Bond (1955)
2. Ferguson (1958)

Biological Phenomena Reported Occurring in a Thermal Range of 70° to 75°F.

Ellis[1] presented a table of summer-time (hot weather) temperatures of inland streams of the United States. Headwater streams in mountainous regions were excluded. Summer temperatures below 64.2°F. were found for 13% of our streams. Summer temperatures between 64.4° and 71.4°F., and summer temperatures between 71.6° and 78.6°F., were represented by 16% and 35% respectively. Based on these few data we can presume that approximately 45% of our inland streams, exclusive of mountainous headwater regions, have peak summer temperatures below 75°F. These streams represent a major segment of our recreational waters because they support trout and salmon, which, in turn, support the most sophisticated form of angling. Sport fishermen are most concerned about two critical (to the fisherman) temperature levels in natural waters. The first of these is that temperature which will alter trout waters so that they become warm-water fish waters. The second is that temperature level that is high enough to eliminate any successful angling.

__Effects of Exposure__ The upper lethal temperature (at which 50% of the fish died in 24 hours) was found[2] to be 71.6°F. for "kakanee" fry (__Oncorhynchus nerka kennerlyi__) and 73.6°F. for the leopard dace (__Rhinichthys falcatus__) in British Columbia.

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1. Ellis (1937)
2. Black (1953)

Compound Stress Effects

Angelovic[1] studied the effect of temperature plus fluoride on rainbow trout (Salmo gairdneri). He observed that no lethal effects were attributable to temperature alone except at 75°F. (the highest temperature with which he experimented), and here there was a high per cent of mortality due to temperature.

The mean oxygen concentration lethal to brook trout (Salvelinus fontinalis) at 70°F. was 2.54 ppm.[2] For rainbow trout (Salmo gairdneri) this concentration, at 71°F., was 1.82 ppm.

An extensive study on the tolerance of striped bass (Roccus saxatilis) and American shad (Alosa sapidissima) to changes in salinity and temperature was made[3]. Abrupt transfers of fish were made at different temperatures and salinities. With adult striped bass a 10% (one of ten fish) mortality occurred at the widest range and salinity change used. This was a change from salt water (at 35°/00 salinity) at 45°F. to fresh water at 74°F. No deaths at lesser changes occurred. When acclimating adults of these two species from normal water temperatures of 55°F. to 74°F. distress and mortality occurred. When returned to water of normal temperatures the fish immediately resumed natural activity. The author suggested that this was a failure of the seasonal physiological balance of the fish to adjust to out-of-season temperatures.

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1. Angelovic (1960)
2. Burdick, Lipschuetz, Dean and Harris (1954)
3. Tagatz (1961)

Effects on Feeding and Growth

In experimenting with guppies (Lebistes reticulatus)[1] it was found that the fastest growth rate was in a thermal range beginning at 73.4°F. (and extending to 77°F.).

Effects on Reproduction and Development

Hubbs[2] compared temperature tolerances of eggs and larvae of four ethostomatine fish. The dusky darter (Percina sciera) and logperch (Percina caprodes) had eggs and larvae with a narrow thermal tolerance. The former survived at 71.6° to 80.6°F., the latter at 71.6° to 78.8°F.

In a study[3] on smallmouth bass (Micropterus dolomieu) eggs at incubatory temperatures it was found that temperature changes in the thermal range of 70° to 75°F. were not injurious. At 75°F. the mean incubation period for the eggs was about two and one-quarter days.

Upper lethal temperatures for Atlantic herring (Clupea harengus)eggs were reported[4] to be 71.6° to 75.2°F.

Effects on Movement and Activity

The optimum activity range for the largemouth bass (Micropterus salmoides)begins at 71.6°F. (and extends to 84.2°F.)[5].

The roach (Rutilus rutilus) had an increase in its oxygen threshold from 0.6 mg/l at 59°F. to 1.6 mg/l at 73.4°F.[6]

Adjustment to Temperature

The ultimate upper lethal temperature for lake trout (Salvelinus namaycush) was reported[7] to be 74.3°F. This is one of the lowest on record.

1. Gibson and Hirst (1955)
2. Hubbs (1961a)
3. Webster (1945)
4. Blaxter (1960)
5. Johnson and Charlton (1960)
6. Privolnev (1963)
7. Gibson and Fry (1954)

The upper lethal temperature for alevins of salmon (presumably Salmo salar), sea trout (probably sea-run rainbow trout, (Salmo gairdneri) and brown trout (Salmo trutta) reared at 41° to 42.8°F. has been reported[1] to be 73.4°F.

The preferred temperature of yellow perch (Perca flavescens) had a mean of 73.4°F. (mode, 76.1°F.) for fish acclimated to 59°F., and a mean of 73.5°F. (mode, 70.7°F.) for fish acclimated to 68°F.[2] The preferred temperature for the salt-water greenfish (Girella nigricans) was given as 74.3°F. The preferred temperature for the burbot (Lota lota lacustris) was given as 70.1°F.

An upper incipient lethal temperature of 70.3°F. for yellow perch (Perca flavescens) acclimated to 41°F. has been reported.[3]

Roach (Rutilus rutilus), given a temperature gradient, will eventually select a temperature of about 73.4° to 75.2°F. for residence[4].

Environmental Conditions

Tarzwell[5] discussed the temperature limits of trout-water and presented several field observations. For brook trout (Salvelinus fontinalis) to do well summer stream temperatures ranging between 52° and 68°F. are necessary. Although the brook trout can survive higher temperatures, streams with higher temperatures are not good trout streams. In two Michigan streams with summer temperatures higher than 75°F. Tarzwell found that trout composed 9.6% of the fish population in one stream, and 15% in the second. In a nearby cold stream, trout

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1. Bishai (1960)
2. Ferguson (1958)
3. Iezzi, Filson and Myers (1952)
4. Alabaster and Downing (1958)
5. Tarzwell (1957)

represented 96% of the fish population. As Tarzwell pointed out, while temperatures higher than the optimum may not kill trout directly, they produce unfavorable environmental conditions for trout and permit the development of coarse fish populations at the expense of the trout population. For good trout production water temperatures must be limited to a favorable thermal range.

The Northwest Miramichi River is part of the famous Miramichi complex supporting Atlantic salmon (*Salmo salar*) and searun rainbow trout (*Salmo gairdneri*) populations. Wurtz[1] found July temperatures as high as 72°F. in this stream. Salmonid fishes would not be expected to maintain populations in waters that commonly exceed 75°F.

Among Ferguson's[2] accumulated field data of fish living at summer temperatures in a thermal range of 70° to 75° are: spotted bass (*Micropterus punctulatus*) at 74.3° to 75.9°F., the walleye (*Stizostedion vitreum*) at 73°F., gizzard shad (*Dorosoma cepedianum*) at 72.5° to 73.4°F., freshwater drum (*Aplodinotus grunniens*) at 70.8° to 71.9°F., the yellow perch (*Perca flavescens*) at 70.1°F., and the smallmouth bass (*Micropterus dolomieu*) at 70.5°F.

The redeye bass (*Micropterus coosae*) occurs in the Chipola River (Florida) where annual water temperatures range from 50° to 75°F.[3] Other than the redeye bass, the principal species in the river were found to be largemouth bass (*Micropterus salmoides*),

1. Wurtz (previously unpublished)
2. Ferguson (1958)
3. Parsons and Crittenden (1959)

warmouth (*Chaenobryttus* "*coronarius*"), bluegill sunfish (*Lepomis macrochirus*), spotted sunfish (*Lepomis punctatus*), redbreast sunfish (*Lepomis auritus*), southern rock bass (*Ambloplites rupestris ariommus*), redfin pickerel (*Esox americanus*), yellow bullhead (*Ictalurus natalis*), channel catfish (*Ictalurus punctatus*), flat bullhead (*Ictalurus platycephalus*), speckled madtom (*Noturus leptacanthus*),spotted sucker (*Minytrema melanops*), blacktail shiner (*Notropis venustus*), Alabama shad (*Alosa alabamae*), carp (*Cyrpinus carpio*) and striped mullet (*Mugil cephalus*). Twenty other species have been recorded from the river.

The academy of Natural Sciences of Philadelphia undertook an intensive stream study program in Pennsylvania in 1948[1,2]. Of the stream locations studied, 17 had recorded temperatures in the thermal range of 70° to 75°F. One of these stations was studied twice. This station, with one other, was considered polluted. These three collections were made at water temperatures of 70.1°, 73.5° and 73.7°F. The resident, macro-invertebrate organisms consisted of 19, 15 and 8 species respectively. The fish numbered 7, 10 and 2 species respectively. The station studied twice was on the Conestoga Creek and includes the first two sets of data as given here. The station with a temperature of 73.7°F. was on Lititz Run, a tributary of the Conestoga.

Seven of the stations studied were considered to be healthy. Water temperatures at these stations ranged from 70.6° to 74.8°F. The number of macro-invertebrate organisms found ranged from 32 to 86 species. The number of fish found ranged from 8 to 16 species. The Brandywine Creek and the Conestoga Creek, with three of its tributaries, were represented among the eight stations.

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1. Anon (1949)
2. Patrick (1949)

Four of the stations studied were considered to be atypical. Their temperature ranged from 72.5° to 74.3°F.;the number of macro-invertebrates ranged from 5 to 27 species; the number of fish ranged from 2 to 9 species. These four stations were all on tributaries of the Conestoga Creek.

Another four stations were considered to be semi-healthy. Their temperatures ranged from 70.1° to 72.8°F.; the number of macro-invertebrate organisms ranged from 24 to 32 species; the number of fish ranged from 1 to 13 species. Two of these stations were on the Brandywine Creek while the other two were on tributaries of the Conestoga Creek.

Biological Phenomena Reported Occurring in a Thermal Range of 75° to 80°F.

At temperatures above 75°F. field observations on salmonids are rare, and experimental studies tend to simply point out an upper lethal temperature.

Effects of Exposure — The alevins of salmon (presumably *Salmo salar*), "Sea trout" (probably sea-run rainbow trout, *Salmo gairdneri*) and brown trout (*Salmo trutta*) had 50% survival for five days at 75.2°F.[1]

Compound Stress Effects — A mean lethal oxygen concentration of 1.08 and 1.15 ppm. at 80°F. for smallmouth bass (*Micropterus dolomieu*) has been reported[2].

Effects on Reproduction and Development — Of all the stages in the life history of the sea lamprey (*Petromyzon marinus*) the eggs have the most limiting thermal requirements[3]. Successful hatching only occurs between 59°F. and 77°F.

Effects on — In brook trout (*Salvelinus fontinalis*) a high frequency of movement at a pre-lethal temperature of 75.2°F. was found[4]. The fish died at 78.8°F.

For all practical purposes 71.6° to 84.2°F. apparently represented the optimum range for activity in the largemouth bass[5].

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1. Bishai (1960)
2. Burdick, Lipschuetz, Dean and Harris (1954)
3. McCauley (1963)
4. Fisher and Sullivan (1958)
5. Johnson and Charlton (1960)

An increase in the oxygen threshold was found[1] associated with increased temperature. The Atlantic salmon (Salmo salar) increased from 1.51 mg/l at 59°F. to 2.85 mg/l at 77°F. A corresponding increase for the perch (Perca fluviatilis) at the same temperatures was from 0.4 mg/l to 1.4 mg/l. The pink salmon (Oncorhynchus gorbuscha) had an oxygen threshold increase from 1.99 mg/l at 60.8°F. to 3.36 mg/l at 77°F.

Adjustment to Temperatures

The upper lethal temperature for the "Kamloops" trout (Salmo gairdneri "kamloops") was recorded[2] at 75.2°F. with a "probable acclimation temperature" of 52.7°F. For the brook trout (Salvelinus fontinalis) the upper lethal temperature was also recorded as 75.2°F., but with a "probable acclimation temperature" of 51.8°F. In an earlier work[3] the upper lethal temperature of "kamloops" trout fingerlings was given as 75.2°F. with an acclimation temperature of 51.8°F.

Spaas[4] studied alevin, fry and paar of Atlantic salmon (Salmo salar), "sea trout" (as Salmo trutta trutta) and brown trout (as Salmo trutta fario). Mean lethal temperature for the brown trout alevin was 77.9°F., for yearling brown trout 78.6°F., and for brown trout paar 84.2°F. The mean lethal temperature for the sea trout yearlings was 79.5°F.

An upper lethal temperature of 77°F. for the brook trout (Salvelinus fontinalis) with a moderate respiratory sensitivity has been reported[5].

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1. Privol'nev (1963)
2. Black (1955)
3. Black (1953)
4. Spaas (1960)
5. Fry in Brown (1957)

The ultimate upper lethal temperature for the brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) was reported[1] to be 77.5°F., and for Oncorhynchus species, 74.8° to 77.2°F.

The preferred temperature of the largemouth bass (Micropterus salmoides) has been indicated[2] to be 78.8°F.

The final temperature preferendum for yellow perch (Perca flavescens) was given[3] as 75.5°F. but indications are that current work will raise this to 76.4°F. For yellow perch acclimated to 77°F. the mean preferred temperature was 76.1°F. (mode. 75.2°F.) and for specimens acclimated to 86°F. the mean preferred temperature was 78°F. (mode, 79.7°F.).

The final temperature preferenda that fall within a thermal range of 75° to 80°F. for two fish were reported to be 75.2°F. for the muskellunge (Esox masguinongy) and 78.8°F. for the grass pickerel (Esox vermiculatus).

The upper lethal temperature for the redside minnow (Richardsonius balteatus) was given[4] as 77°F. (and also as 81.6°F.); for the prickly sculpin (Cottus asper) as 75.3°F.; and for the yellow perch (Perca flavescens) as 79.7° in the winter and 84.3°F. in the summer.

At an acclimation temperature of 41°F. the upper incipient lethal temperature for the white sucker (Catostomus commersoni) was 79.3°F., for the blacknose dace (Rhinichthys atratulus) it was 79.7°F., for the creek chub (Semotilus atromaculatus) it was 76.5°F.,

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1. Gibson and Fry (1954)
2. Fowler (1940)
3. Ferguson (1958)
4. Black (1953)

for the bluntnose minnow (*Hyborhynchus notatus*) it was 78.8°F., and for the emerald shiner (*Notropis atherinoides*) it was 73.8°F. For the yellow perch (*Perca flavescens*) acclimated to 50°F. the upper incipient lethal level was 77°F.[1]

Streams subjected to hot water discharges may have coarse fish populations reduced when mean daily water temperatures reach 86°F.[2] Such populations may increase when mean daily water temperatures fall below 78.8°F.

The upper end of the guppy's (*Lebistes reticulatus*) optimum thermal range is 77°F.[3] (The lower end was given as 68°F.)

Largemouth bass (Micropterus salmoides) were observed[4] living in waters with summer temperatures of 79.8° to 83.8°F., and spotted bass (*Micropterus punctulatus*) at natural summer temperatures of 74.3° to 75.9°F.

The Escambia River, Florida, supported a resident population of macro-invertebrate organisms composed of 90 species[5]. The highest recorded water temperature during the survey was 72.5°F., but 78.8°F. has been recorded for this river (National Water Quality Network, data of Oct. 1, 1959 through Sept. 30, 1960).

In a study by the Academy of Natural Sciences of Philadelphia,[6] an unpolluted station on Little Muddy Creek (Pennsylvania), with a recorded temperature of 75.5°F., had a resident population of 61 macro-invertebrate species and 10 fish species. An unpolluted station on Cocalico Creek with a recorded temperature of 75.7°F. had a resident population of 33 macro-invertebrate species and 15 fish species.

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1. Iezzi, Filson and Myers (1952)
2. Alabaster (1962)
3. Gibson (1954)
4. Ferguson (1958)
5. Wurtz and Roback (1955)
6. Anon. (1949)

Studies by Consulting Biologists, Inc.[1] on the Wissahickon Creek (near Philadelphia, Pa.) extended over a four-year period. Recorded water temperatures in the fall of the year ranged from 60.8° to 76°F. During the course of this program a total of 136 species of macro-invertebrate species was collected as well as 18 species of fish. Although no trout were captured this stream is annually stocked with trout on a put-and-take fisheries basis. The trout do not form part of the resident population.

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1. Anon. (1961)

Biological Phenomena Reported Occurring in a Thermal Range of 80° to 85°F.

Wurtz[1] recommended a stream classification system for Pennsylvania. Among the several categories proposed was "Intermediate Streams." This category was defined as, "...those streams which maintain some flow at all times; which have scouring velocities during the spring months at least; which have stable bottoms; which have maximum, natural, warm-weather temperatures below 85°F.; and which are able to support a resident, breeding population of smallmouth bass (*Micropterus dolomieu*) and/or walleye pike (*Stizostedion vitreum*)." This proposed stream category was designed to recognize that, although trout angling may not be possible other satisfactory angling could be achieved. Ellis[2] indicated that 31% of our inland streams, exclusive of mountainous headwater regions, have peak summer temperature between 78.8° and 85.8°F. Salmonid fish would not be found in these streams. As a matter of fact, Ellis indicated that 55% of our inland streams are not, by nature, suitable for cold-water fisheries.

Virtually the last of the literature references to salmonid fishes in relation to temperature maxima occur in the thermal range of 80° to 85°F.

Effects on Feeding and Growth	Maximum growth of largemouth bass (*Micropterus salmoides*) fry is found[3] at temperatures ranging from 81.5° to 86°F.

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1. Wurtz in Anon. (1960)
2. Ellis (1937)
3. Strawn (1961)

Effects on Reproduction and Development

There was no survival of the eggs and larvae of the orangethroat darter (*Etheostoma spectabile* at temperatures above 80.6°F.[1]

Effects on Movement and Activity

The northern pike (*Esox lucius*) had an increase in its oxygen threshold from 0.72 mg/l at 59°F. to 1.4 mg/l at 84.2°F.[2]

Adjustment to Temperature

The mean lethal temperature for the alevin of Atlantic salmon (*Salmo salar*) was found[3] to be 81.6°F., for yearlings, 83.3°F., and for the paar, 85.6°F. The last appears to be the highest published temperature associated with a salmonid fish. The same author also found mean lethal temperatures for the paar of brown trout (as *Salmo trutta fario*) at 84.2°F., and of sea trout (as *Salmo trutta trutta*) at 84.6°F. The ultimate upper lethal temperature for Atlantic salmon (*Salmo salar*) has been reported[4] as occurring at about 80.6°F.

In reviewing past experimental work, Ferguson[5] listed two species with upper temperature preferenda between 80° and 85°F. These were the goldfish (Carassius auratus) with a final preferendum of 82.5°F., and the smallmouth bass (*Micropterus dolomieu*) with a final preferendum of 82.4°F.

Meuwis and Heuts[6] referred to work by Schaeperclaus wherein the optimum temperature for carp (*Cyprinus carpio*) was given as 80.6°F.

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1. Hubbs and Armstrong (1962)
2. Privol'nev (1963)
3. Spaas (1960)
4. Gibson and Fry (1954)
5. Ferguson (1958)
6. Meuwis and Heuts (1957)

Two papers[1,2] listed upper lethal temperatures between 80° and 85° for several species of fish. These included: longnose sucker (*Catostomus catostomus*) at 80.4°F., peamouth (*Mylocheilus caurinum*) at 80.6°F., redside shiner (*Richardsonius balteatus*) at 81.6°F., largemouth bass (*Micropterus salmoides*) at 83°F., pumpkinseed sunfish (*Lepomis gibbosus*) at 82.4°F., squawfish (*Ptychocheilus oregonensis*) at 85°F., largescale sucker (*Catostomus macrocheilus*) at 85°F., and summer-acclimated yellow perch (*Perca flavescens*) at 84.3°F.

Iezzi, Filson, and Myers[3] presented previously published data by Hart[4]. When acclimated at 50°F. the upper incipient lethal temperature for the white sucker (*Catostomus commersoni*) was 81.9°F., for the blacknose dace (*Rhinichthys atratulus*) it was 83.8°F., for the creek chub (*Semotilus atromaculatus*) it was 81.1°F., for the bluntnose minnow (*Hyborhynchus notatus*) it was 83.1°F., for the fathead minnow (*Pimephales promelas*) it was 82.8°F., for the common shiner (*Notropis cornutus*) it was 83.5°F., and for the emerald shiner (*Notropis atherinoides*) it was 80.1°F. When acclimated to 59°F. the upper incipient lethal temperature for the white sucker was 84.7°F., for the creek chub it was 84.7°F., for the emerald shiner it was 84°F., and for the yellow perch (*Perca flavescens*) it was 81.9°F.

The LD_{50} (i.e. the conditions under which 50% of the sample died) for several species of fish has been reported[5]. The LD_{50} was interpreted as the upper lethal temperature. For black crappie

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1. Black (1953)
2. Black (1955)
3. Iezzi, Filson and Myers(1952)
4. Hart (1947)
5. Trembley (1961a)

(*Pomoxis nigromaculatus*) acclimated to 45°F. the LD_{50} was 84°F. Other species acclimated to 45°F. included walleye (*Stizostedion vitreum*) with an LD_{50} of 84°F., comely shiner (*Notropis amoenus*) with an LD_{50} of 84°F., and rock bass (*Ambloplites rupestris*) with an LD_{50} of 85°F.

Environmental Conditions

Ferguson[1] included no field observations of fish living in waters with summer temperatures above 80°F. with the exception of largemouth bass (*Micropterus salmoides*) in the Norris Reservoir (Tennessee) at 79.8° to 83.8°F.

Two groups of rainbow trout (*Salmo gairdneri*) were raised to yearlings in hard and soft water respectively[2]. Those reared in soft water had a greater resistance to thermal stress. Tests were done at 80.6, 82.4 and 84.2°F. Increased salinity in the test medium resulted in an increase in thermal resistance.

The Academy of Natural Sciences of Philadelphia[3] reported on four stream locations in Pennsylvania where recorded summer temperatures fell in a thermal range of 80° to 85°F.

Three of these locations were on the Brandywine Creek. At 80.2°F. there was a population of 59 macro-invertebrate species, although no fish were found. At 82°F. there were 11 macro-invertebrate species and one fish species (the mummichog, *Fundulus hetroclitus*). The latter station was polluted. At 82.4°F. there were 25 macro-invertebrate species and seven fish species. The seven fish were: grass pickerel (*Esox americanus vermiculatus*),

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1. Ferguson (1958)
2. Craigie (1963)
3. Anon. (1949)

white sucker (Catostomus commersoni), golden shiner (Notemigonus crysoleucas), satinfin shiner (Notropis analostanus), spottail shiner (Notropis hudsonius), banded killifish (Fundulus diaphanus) and the Johnny darter (Etheostoma nigrum).

The fourth Academy recorded was from Mill Creek (Conestoga Basin) with a water temperature of 82.4 F. This location, which was considered to be polluted, had a macro-invertebrate population of 14 species with four fish species. The latter were: carp (Cyprinus carpio), brown bullhead (Ictalurus nebulosus), banded killifish (Fundulus diaphanus), and pumpkinseed sunfish (Lepomis gibbosus).

Biological Phenomena Reported Occurring in a Thermal Range of 85° to 90°F.

Effects of Exposure

An estimated ultimate 24-hour lethal temperature for a scud (*Gammarus pseudolimnaeus*) has been reported[1] to be 85.3°F. Other species of Crustacea had lethal temperatures above 90°F.

Fat (overfed) and lean (normal food supply) channel catfish (*Ictalurus punctatus*) were studied[2] for rate of oxygen consumption. Fat catfish had the higher rate at 77°F., but the difference disappeared when the water temperature was suddenly raised to 86°F. Increased temperature substantially increased metabolic activity of both groups, but there was a progressive decrease with time. On the fourteenth day the rates were only slightly higher at 86°F. than at 77°F.

Experiments[3] indicate that the upper thermal limit for perch (*Perca fluviatilis*) is 86° to 87.8°F. since they cannot survive higher temperatures for more than a few hours.

Compound Stress Effects

According to one worker[4] both genetic composition and early thermal history influenced resistance to high temperatures as well as acclimation before an experiment. In some experimental work[5] on cold death in guppies, fish acclimated to 73.4°F. survived an oxygen-depleted water at 69.8°F. for 15 minutes. However, 50% of the fish died under the same conditions when acclimated to 86°F. It was concluded that tolerance to lack of oxygen was inversely proportional to acclimation termperature.

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1. Sprague (1963)
2. Moss and Scott (1964)
3. Weatherley (1963)
4. Gibson (1954)
5. Pitkow (1960)

The mean asphyxial concentration of oxygen for roach (Rutilus rutilus) at 86° and 89.6°F. was found[1] to be 0.8 mg/l. In a second paper the same author stated that roach cannot fully acclimate at rates faster than 0.09°F. (1/20 C) per hour. When acclimated to 68°F. the death temperature range at a temperature increase rate of 0.18°F. per hour was 86° to 89.6°F. with a mean of 88.5°F.

Effects on Feeding and Growth

The upper end of the thermal range for best growth of largemouth bass (Micropterus salmoides) fry was found[3] to be 86°F. Guppies (Lebistes reticulatus) grew very slowly at 89.6°F.[4]

Effects on Reproduction and Development

Fry of largemouth bass (Micropterus salmoides) hatched at temperatures below 86°F., and reared at 90.5°F., grew more slowly than fry reared at 86°F.[5] Largemouth bass eggs put directly into water with a temperature of 90.5°F. died.

Admustment to Temperatures

In this thermal range there has been reported[6] a final upper temperature preferenda for three species: that for the largemouth bass (Micropterus salmoides) was 86° to 89.6°F., for the carp (Cyprinus carpio) it was 89.6°F., and for the pumpkinseed sunfish (Lepomis gibbosus) it was 88.7°F.

An upper lethal temperature of 86°F. for the white sucker (Castostomus commersoni) with a "probable acclimation temperature" of 68°F. has been reported[7]. Upper lethal temperatures resulting

1. Cocking (1959a)
2. Cocking (1959b)
3. Strawn (1961)
4. Gibson and Hirst (1955)
5. Strawn (1961)
6. Ferguson (1958)
7. Black (1955)

in a 50% kill at 86.1°F. for the pumpkinseed sunfish (Lepomis gibbosus and 87.8° to 93.2°F. for carp (Cyprinus carpio) acclimated to 68°F. has also been reported[1].

Pitt, Garside and Hepburn[2] made a study of temperature selection by the carp (Cyprinus carpio). Selected temperatures for fish acclimated to six different temperatures were found. The acclimation temperatures were 50°, 59°, 68°, 77°, 86° and 95°F. The selected temperatures were 62.6°, 77°, 80.6°, 87.8°, and 89.6°F. The final preferendum for the carp was 89.6°F.

An incipient upper lethal temperature of 86.4 F. has been reported[3] for the brown bullhead (Ictalarus nebulosus) acclimated to 50°F. With an acclimation temperature of 59°F. the incipient upper lethal temperature for the blacknose dace (Rinichthys atratulus) was 85.3°F., for the bluntnose minnow (Hyborhynchus notatus), 87.1°F.; for the common shiner (Notropis cornutus), 86.5°F.; and for the brown bullhead, 89.2°F. With an acclimation temperature of 68°F. the incipient upper lethal temperature for the creek chub (Semotilus atromaculatus) was 86.5°F.; for the bluntnose and fathead (Pimephales promelas) minnows, 89.1°F.; and for the common shiner, 87.8°F. With an acclimation temperature of 77°F. the incipient upper lethal temperature for the creek chub was 86.5°F.; for the common shiner, 87.8°F.; for the emerald shiner (Notropis atherinoides), 87.2°F.; and for the yellow perch (Perca flavescens), 85.5°F.

Roach (Rutilus rutilus) were found[4] to move away from temperatures of 84.2° to 86°F. These fish could live for at least 24 hours at 87.8°F.

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1. Black (1953)
2. Pitt, Garside and Hepburn (1956)
3. Iezzi, Filson and Myers (1952)
4. Alabaster and Robertson (1961)

Several fish species were acclimated[1] to 45°F. and then the LD_{50} was measured. The white sucker (*Catostomus commersoni*) had an LD_{50} of 86°F. Several species had an LD_{50} of 87°F.; these were the common shiner (*Motropic cornutus*), spottail shiner (*Notropis hudsonius*), fallfish (*Semotilus corporalis*), and the largemouth bass (*Micropterus salmoides*). Species with an LD_{50} of 88°F. were: swallowtail shiner (*Notropis procne*), golden shiner (*Notemigonus crysoleucas*), Johnny darter (*Etheostoma nigrum*) and creek chub (*Semotilus atromaculatus*). Species with an LD_{50} of 89°F. were: bluegill sunfish (*Lepomis macrochirus*), "redbelly" sunfish (?*Lepomis auritus*) and blacknose dace (*Rhinichthys atratulus*). The satinfin shiner (*Notropis analostanus*) and the fathead minnow (*Pimephales promelas*) had LD_{50} values of 90°F.

When fish were acclimated to 52°F., higher LD_{50} values were realized. The rock bass (*Ambloplites rupestris*) had an LD_{50} of 87°F., as did the fallfish (*Semotilus corporalis*). Species with an LD_{50} of 88°F. were: white sucker (*Catostomus commersoni*), golden shiner (*Notemigonus crysoleucas*), common shiner (*Notropis cornutus*) and spottail shiner (*Notropis hudsonius*).

An upper lethal temperature for the white sucker (*Catostomus commersoni*) was listed[2] as 86°F., and for the common shiner (*Notropis cornutus*) as 89.6°F. These lethal temperatures were associated with high respiratory sensitivity. An upper lethal temperature of 89.6°F. was reported for *Pfrille neogoea*. This was associated with a low respiratory sensitivity.

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1. Trembly (1961a)
2. Fry in Brown (1957)

Carp left continuously in a temperature gradient would be found almost exclusively within a few degrees of 89.6°F.[1]

<u>Environmental Conditions</u> Coarse fish populations were reduced when mean daily water temperatures reached 86°F.[2] One worker[3] suggested that temperate zone streams should not be raised above 86°F. for prolonged periods.

The Academy of Natural Sciences of Philadelphia[4] published the results of a biological survey of the Savannah River below Augusta, Georgia. This was an extensive study covering the four seasons of the year. The maximum river temperature recorded by the Academy group was 85.1°F., and this river supported a resident population of 279 macro-invertebrate species and 38 fish species. These organisms are specifically identified in the report.

Wurtz and Dolan[5] reported on the effects of a thermal discharge into the Schuylkill River (Pennsylvania). Unpublished were temperature data for the river above the point of discharge. The uppermost station had a recorded temperature of 87°F. and a resident population of 32 species of macro-invertebrate organisms. Another station above the discharge had a recorded temperature of 89.6°F. and a resident population of 24 species of macro-invertebrate organisms.

A fresh-water snail (<u>Lymnaea stagnalis</u>) culture died when the culture water reached 86.9°F.[6]

In a study[7] on the effect of warm-water discharges on a river it was found that river-bottom plants and animals decreased in numbers when the water temperature exceeded 86°F.

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1. Fry (1958)
2. Alabaster (1962)
3. Cairns (1956)
4. Anon. (1953)
5. Wurtz and Dolan (1962)
6. Noland and Reichel (1943)
7. Strangenberg and Pawlaczyk (1960)

Biological Phenomena Reported Occurring in a Thermal Range of 90° to 95° F.

Aquatic animals native to the temperate zone are adapted to temperature fluctuations between 39° and 90°F. Some species, of course, range lower while others range higher. If this temperature range were to be extended it would probably be extended further into the colder temperatures rather than the warmer. In general, however, populations composed of diverse species and in balance with their environment would probably be limited to the range suggested.

Tarzwell[1] recommended limiting discharges in the Ohio Valley area so that peak summer temperatures would not exceed 93°F. at any time or place. In more southern waters he recommended that such a peak should probably not exceed 96°F. In general, of course, temperatures would be considerably below these peaks. These limiting maxims were suggested by Tarzwell for waters that were to sustain a well-rounded warm-water fish population. If fish life in any given surface water is a matter of importance to the public in general, then, indeed, these maxima should be observed. They should be permitted very infrequently and for only short periods of time. The duration of any peak loading should certainly be for less than 24 hours. At the same time, however, it must be observed that temperatures in excess of the suggested maxima are by no means completely destructive of aquatic life, nor even of all fish life.

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1. Tarzwell (1957)

Compound Stress Effects When roach (Rutilus rutilus) were subjected[1] to five different rates of temperature-rise, following acclimation at 86°F., it was found that at a rise of 0.09°F. per hour the roach died over the longest temperature range (86.5° to 96.4°F.), and had the highest mean death temperature (91.2°F.)[1].

Effects on Reproduction and Development Largemouth bass (Micropterus salmoides) eggs put into water of 90.5° died[2]. The incipient upper lethal temperatures for fish acclimated to 77°F. was 91.9°F. for the bluntnose minnow (Hyborhynchus notatus) and 95°F. for the brown bullhead (Ictalurus nebulosus)[3]. The fathead minnow (Pimephales promelas), when acclimated to 86°F., had an incipient upper lethal temperature of 91.8°F.

A final preferendum for the bluegill sunfish (Lepomis machrochirus) has been reported[4] at 90.1°F.

Black, in two papers[5,6], listed an upper lethal temperature of 95°F. for the black bullhead (Ictalurus melas melas) when acclimated to 73.4°F. The brown bullhead (Ictalurus nebulosus) was listed as having an upper lethal temperature of 91.9°F. with a "probable acclimation temperature" of 66.2° to 71.6°F.

Channel catfish (Ictalurus punctatus) acclimated to 71.6°F. died a few hours after exposure to 95°F.[7] The same species, acclimated to 86°F., had no mortality within 24 hours at 95°F. With continuous exposure channel catfish died at 89.6° to 91.4°F.

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1. Cocking (1959b)
2. Strawn (1961)
3. Iezzi, Filson and Myers (1952)
4. Ferguson (1958)
5. Black (1953)
6. Black (1955)
7. Cairns (1956)

"Bullheads" (probably Ictalurus nebulosus) survived temperatures of 93.2°F.

At 92.3°F. there was a 50% kill of a sample of roach (Rutilus rutilus)[1]. This 50% level could not be raised by further acclimation.

The acclimation temperature of guppies (Lebistes reticulatus) had a moderate influence on resistance at very high temperatures (up to 100.4°F.), but the effect was less at 95°F., and was lost at 93.2°F.[2]

LD_{50} temperatures for several species of fish at two acclimation temperatures, 45°F. and 52°F. were derived[3]. When acclimated to 45°F. the pumpkinseed sunfish (Lepomis gibbosus) and the channel catfish (Ictalarus punctatus) had an LD_{50} of 91°F. The white catfish (Ictalurus catus) acclimated to 45°F. had an LD_{50} of 92°F. Other species, and their LD_{50} values, acclimated to 45°F. were: brown bullhead (Ictalurus nebulosus) with an LD_{50} of 93°F. and banded killifish (Fundulus diaphanus) with an LD_{50} of 93°F. An unidentified species of crayfish (but, based on location, probably (Orconectes limosus) also had an LD_{50} of 93°F. when acclimated to 45°F.

When acclimated to 52°F. the swallowtail shiner (Notropis procne) had an LD_{50} of 90°F. Under the same conditions the largemouth bass (Micropterus salmoides), the bluegill sunfish (Lepomis macrochirus), the "redbelly" sunfish (?Lepomis auritus) and the channel catfish (Ictalurus punctatus) had an LD_{50} of 95°F. The satinfin shiner (Notropis analostanus) had an LD_{50} of 94°F.

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1. Cocking (1959a)
2. Gibson (1954)
3. Trembley (1961a)

Six fish species with upper lethal temperatures between 90° and 95°F. were studied by another worker[1]. These were the yellow perch (*Perca flavescens*), 91.4°F.; the bluegill sunfish (*Lepomis macrochirus*), the fathead minnow (*Pimephales promelas*), the largemouth bass (*Micropterus salmoides*) and the channel catfish (*Ictalurus punctatus*), 93.2°F.; and the golden shiner (*Notemigonus crysoleucas*), 95°F. These lethal temperatures for the yellow perch and bluegill sunfish were associated with high respiratory sensitivity, for the fathead minnow, golden shiner and largemouth bass they were associated with a moderate respiratory sensitivity, and for the channel catfish the temperature was associated with a low respiratory sensitivity.

The ultimate 24-hour lethal temperature for a fresh-water sowbug, *Asellus intermedius*, and for a scud, *Gammarus fasciatus*, was found[2] to be 94.3°F. For a second scud (*Hyalella azteca*) a corresponding temperature of 91.8°F. was estimated. It was concluded that under natural conditions lethal temperatures would seldom affect distribution of these crustaceans.

Environmental Conditions

In a southern Michigan lake in 1936 Tarzwell observed a bass kill at 94°F., but in Wheeler Reservoir (Tennessee) a temperature of 96°F. did not cause a fish kill.

Seven goldfish (*Carassius auratus*) were trained[3] to push a lever for cold water. The fish very rarely allowed the water temperature of their container to rise above 97.7°F., and rarely lowered it below 92.3°F. The maintained temperature of the experiment was about 95°F.

1. Fry in Brown (1957)
2. Sprague (1963)
3. Rozin and Mayer (1961)

Extreme temperatures were found[1] to range as high as 95°F. at stations where the greenthroat darter (Etheostoma lepidum) was collected.

A ditch draining waste water from a corn products plant in Illinois contained water ranging from 82.4° to 95°F. on a year-round basis[2]. A fresh-water snail (Physa gyrina) lived in the ditch and displayed a maximum rate of reproduction throughout the entire year. The snail occurred in the ditch, which had a linear temperature gradient, up to a temperature of 91.4°F.

Extensive limnological studies[3] of the Mississippi River near Quincy, Illinois, have been made. The mean annual river temperature (surface) was 58.5°F., but the temperature ranged from 32°F. to 92.8°F. At this location the river is quite large, having a mean annual discharge of 514,000 cubic feet per second. It would be of interest to know what aquatic organisms are resident in this stretch of the stream.

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1. Hubbs and Strawn (1957)
2. Agersborg (1932)
3. Dorris, Copeland Lauer (1963)

Biological Phenomena Reported Occurring in a Thermal Range of 95° to 100°F.

Although there are historic records of fish surviving natural temperatures of 100$^{+\circ}$F., this is unusual. Waters with temperatures that regularly exceed 95°F. would not be expected to support a large, or diverse, fish population.

Effects of Exposure

In some experimental work a 25% kill at 95.9°F. in 31 minutes was found[1] for goldfish (*Carassius auratus*) conditioned to eight hours of light per day, and in 41 minutes for fish conditioned to 16 hours of light per day.

A 48-hour median tolerance limit ($= LD_{50}$) for temperature for the California killifish (*Fundulus parvipinnis*) was found[2] at 97.7°F. The 30-minute median tolerance limit was 103.5°F.

Compound Stress Effects

Meuwis and Heuts[3] studied breathing rates in carp (*Cyprinus carpio*) and observed that death occurred in large fish at 95° to 96.8°F.

Fully acclimated roach (*Rutilus rutilus*) held in a constantly increasing temperature (0.09°F. per hour) died over an extended temperature range which reached 96.4°F.[4]

Berg[5] studied oxygen consumption in the fresh-water limpets (*Ancylus fluviatilus* and *Acroloxus lacustris*). The experiments were done at 37.4° to 42.8°F. and at 96.8° to 104°F. *Ancylus fluviatilus* is normally associated with maximum summer temperatures of about 77°F., but at 96.8°F. the oxygen consumption

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1. Hoar (1946)
2. Fry (1957)
3. Meuwis and Heuts (1957)
4. Cocking (1959b)
5. Berg (1952)

indicated that the limpets were not hurt by the temperatures. Death occurred at temperatures above 96.8°F. With Acrolexus lacustris death occured as low as 87.8°F., but oxygen consumption increased up to this temperature level.

Effects on Reproduction and Development Viable fish (minnow species?) eggs were found[1] adhering to the underside of a stone in the Schuylkill River at a water temperature of 98.6°F.

Temperatures of 95° to 98.6°F. for five minutes produced abnormalities in the eggs of the threespine stickleback (Gasterosteus aculeatus[2] .

Adjustment to Temperature The upper lethal temperature for carp (Cyprinus carpio) was found[3] at 96.3°F. with an acclimation temperature of 78.8°F. For the goldfish (Carassius auratus) the upper lethal temperature was 97.9°F. with an acclimation temperature of 78.8°F.

An optimum temperature for seven trained goldfish was found[4] to be approximately 95°F. An incipient upper lethal temperature of 97.9°F. for goldfish acclimated to 77°F. has been reported[5].

Trembly[6] reported LD_{50} temperatures that fall into the thermal range of 95° to 100°F. for several species of fish. When acclimated to 45°F. the mummichog (Fundulus heteroclitus) had an LD_{50} of 99°F. Interestingly, an unidentified tadpole (probably a species of Rana) also had an LD_{50} of 99°F. when acclimated to 45°F.

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1. Wurtz (previously unpublished)
2. Swarup (1959)
3. Black (1953)
4. Rozin and Mayer (1961)
5. Iezzi, Filson and Myers(1952)
6. Trembley (1961a)

When acclimated to 52°F. the white catfish (*Ictalurus catus*) and the brown bullhead (*Ictalurus nebulosus*) had LD_{50} values of 97°F., while the banded killifish (*Fundulus diaphanus*) had an LD_{50} of 98°F.

When acclimated to 75°F. the largemouth bass (*Micropterus salmoides*) had LD_{50} values of 97° and 98°F., while the rock bass (*Ambloplites rupestris*) had LD_{50} values of 97.5° and 99.5° F. When acclimated to 76°F. the largemouth bass and the bluegill sunfish (*Lepomis macrochirus*) had LD_{50} values of 97° and 99°F.

An upper lethal temperature of 96.8°F. for the gizzard shad (*Dorosoma cepedianum*) was found[1] associated with high respiratory sensitivity. An upper lethal temperature of 96.8°F. was also reported for the brown bullhead (*Ictalurus nebulosus*), but associated with a low respiratory sensitivity.

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1. Fry in Brown (1957)

Biological Phenomena Reported Occuring in a Thermal Range of 100° to 105°F.

Effects of Exposure — There is an upper temperature limit beyond which each species cannot survive for more than a few hours regardless of acclimation. This was below 104°F. for the five species studied in one work[1]. These five were the bluegill sunfish (Lepomis macrochirus), channel catfish (Ictalurus punctatus), "bullhead" (?Ictalurus nebulosus), top minnows (Fundulus sp.), and "pin perch" (?pinfish, Lagodon rhomoboides), a marine species.

Compound Stress Effects — Small carp (Cyprinus carpio) have been found[2] to have an upper lethal temperature of 100.4° to 102.2°F. Larger carp had lower lethal maxima at 95° to 96.8°F. This paper noted that decreased resistance to high temperature with increase in size is not a general trend among fish. However, three types of fish exist - those with increasing, those with stationary, and those with decreasing resistance to high temperature with increase in size. It is obvious that the correlation could be associated with age rather than size.

Adjustment to Temperature — Goldfish (Carassius auratus) were reported[3] to have an incipient upper lethal temperature of 101.5°F. when acclimated to 86°F.

Trembley reported temperatures resulting in a 50% kill (i.e. LD_{50}) of test fish at several acclimation temperatures. The largemouth bass (Micropterus salmoides) acclimated to 80°F. had

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1. Cairns (1955)
2. Meuwis and Heuts (1957)
3. Iezzi, Filson and Myers (1952)
4. Trembley (1960b)

an LD_{50} of 100° to 102°F. The bluegill sunfish (*Lepomis macrochirus*) acclimated to 79°F. had an LD_{50} of 103°F. In this paper Trembley also reported capturing a single specimen of the pumpkinseed sunfish (*Lepomis gibbosus*) in water at 100°F. However, this fish was sluggish and in poor condition.

In a continuing study on the Delaware River Trembley[1] reported an LD_{50} of 103°F. for two species of killifish (*Fundulus diaphanus* and *F. heteroclitus*) acclimated to 90°F. These species were observed living, and apparently spawning, in water with temperatures up to 100°F. With a modification of the testing apparatus Trembley believed the results presented in the 1961 report (herein 1961a) were more reliable than those presented in his 1960 (herein 1960b) report.

Trembley[1] also reported an LD_{50} of 101°F. for the "redbelly" sunfish (?*Lepomis auritus*), an LD_{50} of 101.5°F. for the bluegill sunfish (*Lepomis macrochirus*) and an LD_{50} of 102°F. for the pumpkinseed sunfish (*Lepomis gibbosus*) when acclimated to 70°F.

Environmental Conditions

Bailey[2] reported on a high-temperature fish kill occurring in a small (1/4 acre) shallow (5-inch maximum depth) residual pool in southern Michigan. On a sunny afternoon the water temperature was 100.4°F. The following day the temperature had dropped to 95°F. The fish killed included rock bass (*Ambloplites rupestris*), mudminnow (*Umbra limi*), chubsucker (*Erimyzon sucetta*), golden

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1. Trembley (1961a)
2. Bailey (1955)

shiner (Notemigonus crysoleucas), blackchin shiner (Notropis heterodon), blacknose shiner (Notropis heterolepis), a shiner species (as Notropis deliciosus), bluntnose minnow (Pimephales notatus), brown bullhead (Ictalurus nebulosus), yellow bullhead (Ictalurus notalis) , brindled madtom (Noturus miurus), tadpole madtom (Noturus gyrinus) and Iowa darters (Etheostoma exile).

Survivors included a yearling largemouth bass (Micropterus salmoides), green sunfish (Lepomis cyanellus), bluegill sunfish (Lepomis macrochirus),longear sunfish (Lepomis megalotus peltastes), and pumpkinseed sunfish (Lepomis gibbosus). Survival among less tolerant species was limited to immature fish. These included chubsucker (Erimyzon sucetta), blackchin shiner (Notropis heterodon) bluntnose minnow (Pimephales notatus), Brown bullhead (Ictalurus nebulosus) and tadpole madtom (Noturus gyrinus).

Trembley[1] reported differences between the body temperature of dying fish and the water from which they were taken. Among bluegill sunfish (Lepomis macrochirus) seven taken from water at 103°F. had body temperatures of 100° to 102°F., six taken from water at 102°F. had body temperatures of 102° to 103°F., six others taken from water at 102°F. had body temperatures of 100°F., five taken water at 99°F. had body temperatures of 101°F., six taken from water at 99°F. had body temperatures of 99°to 100°F., and three further specimens taken from water at 99°F. had body temperatures of 99°F. Since Trembley is an accomplished field biologist we can accept these figures as real. The high and low body temperatures relative to ambient water temperatures is inexplicable. In water of 95°F. Trembley found golden shiners (Notemigonus crysoleucas) with body temperatures ranging from 92° to 93°F.

1. Trembley (1960b)

In the same report the brown bullheads (Ictalurus nebulosus was observed living in a lagoon with a temperature gradient of 89° to 106°F. The fish were swimming in the water at the low end of the thermal gradient (89° to 90°F.). However, these fish would swim into 104°F.-water to strike at worms tossed in. Although they did not remain long, one, quite sluggish, was caught. It had a body temperature of 96°F.

A number of five - to six-inch American eels (Anguilla rostrata) were found[1] dead in a lagoon with a water temperature of 104°F.

Fresh-water snails (Viviparus malleatus) died when held at 99.5°F.[2]

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1. Trembley (1960b)
2. Hutchinson (1947)

Biological Phenomena Reported Occurring at Temperatures above 105°F.

Compound Stress Effects

The fresh-water snail (*Australorbis glabratus*), which is a vector for certain schistosomes, has been critically studied[1]. Oxygen consumption by these snails increased through a thermal range of 0.3° to 98.6°F. The snails were definitely damaged by a temperature of 105.8°F.

The authors of the same study observed that pulmonate snails have higher rates of oxygen consumption than operculate snails. Further, those pulmonate snails with haemoglobin, which includes (*Australorbis glabratus*), are apparently independent of oxygen tension.

Adjustment to Temperature

Young goldfish (*Carassius auratus*), with an acclimation temperature of 97.7°F., had an upper lethal temperature of 105.8°F.[2] This work has been widely quoted. Fry[3] in speaking of metabolic rates in goldfish, shows a relatively steep curve at lower temperatures, but the curve flattens out as the lethal temperature is approached. The lethal temperature is given as 104°F.

The upper lethal temperature for *Tilapia* was found[4] to be 107.4°F. This is of interest because this fish, widely cultured in the orient as a protein food source, has been introduced into the southern United States.

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1. VonBrand, Nolan and Mann (1948)
2. Fry, Brett and Clawson (1942)
3. Fry in Brown (1957)
4. Long, Zau and Ving (1961)

<u>Environmental Conditions</u>

All the fish in a small pond near Savannah, Georgia, were killed when the water temperature reached 108°F.[1]

The bottom fauna of the Schuylkill River in Pennsylvania below a heated discharge has been studied[2]. The river here during 1959 had water temperatures at or above 95°F. on 33 days, at or above 100°F. on 13 days, and, on one day, had a maximum water temperature of 106.5°F. This location was supporting a resident population of 19 macro-invertebrate species.

The ultimate maximum temperature for macroscopic invertebrate organisms is well above that for fish. For example, soldier fly larvae (<u>Stratiomyidae</u>) can live in thermal waters at temperatures up to 120°F.[3] These insect larvae represent a highly specialized group, of course, and such hot waters would not support a population composed of a diversity of species.

Some field observations[4] have been made on an aquatic snail (<u>Lymnaea humilus</u>) in Michigan. These snails characteristically crawl from the water and appear to be an incipient amphibious species. They were found on a mud bank with an air temperature of 100.4°F. while the water temperature of the stream was 84.2°F.

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1. Tarzwell (1957)
2. Wurtz (1961b)
3. Usinger (1956)
4. McGraw (1959)

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STATEMENT BY ALBERT H. STEVENSON

HEALTH ASPECTS—THERMAL-ELECTRIC POWER GENERATION [1]

(By Albert H. Stevenson [2])

I appreciate this opportunity to discuss the potential impact of thermal-electric power generation on the health and welfare of the millions of people who live in this region. This is indeed a rare occasion when one of the purposes of this meeting is to anticipate the environmental health problems that may arise in years to come as a consequence of decisions that will have to be made now. The history of our country includes all too few instances of such foresight. We know now that the forces of economic growth, urbanization, and technological progress often produce unplanned and unwanted adverse side-effects on public health and welfare—but we know it only through hindsight.

The aggressive leadership of the Pacific Northwest in bringing together the public and private sector in its power generation planning effort is outstanding. The success of these efforts could serve well as a model for others to emulate.

Our past failure to anticipate and plan for the prevention of environmental health problems has indeed been costly. In every part of the country, rivers and lakes that once were clear and beautiful are now foul and filthy, and the air we must breathe to sustain life is often, instead, a threat to life. President Johnson has described the consequences this way: "Of all the reckless devastations of our natural heritage, none is more shameful than the continued poisoning of our rivers and the air." We must begin to profit from the bitter experience of the past, to insure that this area's future demands for energy will be met without creating a legacy of air and water pollution problems for future generations to solve.

There are no magical ways of preventing such problems. The key—if there is one—lies in the early identification of potential sources of environmental pollution, the selection of the most appropriate plant locations, and the incorporation of effective control measures in the plant design. *The cost of this—no matter how high it may seem—is invariably less than the cost of abatement measures later.* The savings are measurable, not only in dollars and cents, but also in the conservation of human resources. The choice will be made by the people of the Northwest. No one else can make it for them. However, it is important that this choice be made in full awareness of the risks to be run by failing to take advantage of all those measures available for preventing air and water pollution problems associated with thermal power generation.

HEALTH ASPECTS

It is appropriate that we first focus upon the more obvious hazards or insults to man as a result of the defilement or degradation of the environment. These insults may be categorized as chemical, physical, biological, and radiological. Many of the environmental contaminants manifest themselves in acute or chronic syndromes which may be cumulative and/or irreversible in their biological effects on man. In combination they may exert synergistic effects which considerably outweigh their individual effects.

Contaminants of public health concern arising from the operation of thermal power generation facilities are present in the liquid and gaseous waste discharges. As the base load capacity in the Pacific Northwest shifts from hydropower to thermal generation, the fuel reserves of the area and their distribution may effectively limit the number and location of fossil fuel plants. Although

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we must place in proper perspective the ratio of fossil fuel to nuclear power plants, let us briefly cover the impact of these plants on man and his environment.

COAL-FIRED THERMAL POWER PLANTS

In this overview of the future, I should like to outline briefly the major air pollution problems associated with fossil fuel or "conventional" thermal power plants, specifically coal-fired plants, which are most likely to be constructed in the Pacific Northwest. The combustion of coal produces particulate emissions in the form of smoke, fly ash, and some polycyclic hydrocarbons. In addition, there are two important classes of gaseous pollutants—oxides of nitrogen and oxides of sulfur. To one degree or another, all of these pollutants are detrimental to human health and welfare.

Insofar as particulate matter is concerned, the emission rate is primarily a function of fuel quality, plant design, and operation of relatively simple control equipment. The most visible effects of smoke and fly ash are mainly objectionable to the senses and expensive to the pocketbook. Other types of particulates are capable of injuring human health, primarily by enhancing the physiological effects of gaseous pollutants and also by accelerating chemical reactions in the atmosphere, such as the conversion of sulfur dioxide to sulfur trioxide. The latter, for example, can penetrate deeper into the lungs, and by contact and retention produce significant harmful effects, especially among the more susceptible members of the population who have some degree of respiratory impairment.

The oxides of nitrogen—a by-product of all combustion processes—constitute another direct and indirect threat to health. Of these, nitric oxide, which, although relatively harmless at concentrations generally found in urban air, reacts in the presence of sunlight, by a photochemical reaction, to form nitrogen dioxide, which is capable of producing injurious effects on the human respiratory system. These include, for example, irritation of membranes and impairment of defensive mechanisms which protect the body against respiratory infections. They are also suspected of contributing to the development of chronic respiratory disease. In addition, further reaction with hydrocarbons in the atmosphere produces "photochemical smog" which in turn results in secondary effects such as eye and throat irritation.

Of all the pollutants produced by the burning of coal, however, the oxides of sulfur are considered, on a national basis, to be the most important from the standpoint of public health. In fact, in the East and Midwest, power generating plants are responsible for some 40 percent of the sulfur oxides emitted. These compounds—principally sulfur dioxide, sulfur trioxide, and sulfuric acid—are known to produce a wide range of adverse effects on man, animals, vegetation, and materials. The sulfur oxides threaten human health by contributing to the occurrence of chronic pulmonary disease, aggravating the condition of those so afflicted, and increasing susceptibility to acute upper respiratory infections such as the common cold. The sulfur oxides, especially in areas of high humidity, are highly corrosive to metals, stone and concrete. In addition, these contaminants also produce destructive effects on many types of vegetation, including food and forage crops, trees, and ornamental plants. Among these, sulfur oxides are damaging selectively to one species of which Portland is especially proud—the rose.

In its power planning for the future, the Northwest, although not blessed with an abundance of high quality coal reserves, is indeed fortunate that the sulfur content is only about 0.7 percent in comparison to significantly higher values commonly found in fuels used in the East and Midwest which range from 2.0 to 3.5 percent.

Several means of control are available. Briefly, these include site selection, design, and operational considerations such as plant and stack design, fuel selection or alteration, stack gas cleaning equipment, and control of operating procedures in accordance with local meteorological conditions. All these factors should be weighed and optimized in planning the addition of new thermal-electric power generating plants in the major utility systems of tomorrow.

Nuclear power plants

From an air pollution point of view, nuclear power plants afford several advantages over fossil fuel fired plants. For example, since nuclear plants inherently do not require air to burn fuels, as in the normal combustion process, they do not discharge combustion products such as the oxides of sulfur and nitrogen to the atmosphere. Nevertheless, nuclear plants, by their very nature, require special safeguards to prevent environmental contamination and concomitant hazard to human health.

Exhaust gases from "on-line" nuclear plants are routinely passed through condensate traps and banks of high efficiency filters before stack discharge. Airborne effluents from these plants during normal operation are thus virtually free of radioactive particulate matter. Radioactive noble gases such as argon, xenon, and krypton, however, normally are discharged in low concentrations from nuclear power plants. In addition, some isotopes, such as iodine-131, represent a potential internal radiation hazard because of their easy route to the human body through ingestion of cows' milk. In considering the discharge of gaseous radioactivity from nuclear plants, the additive effects from all sources upon the surrounding environment must be thoroughly investigated. Although the emission of iodine-131 from a large plant may be well below acceptable levels, the micrometeorological regime and local agricultural practices may result in iodine-131 concentrations in milk above acceptable levels. The noble gases, being essentially chemically inert, are not normally considered to be an internal hazard because they are not retained in the body. However, they do represent a possible external exposure hazard, especially in the event of abnormal plant operation.

Limited studies to date have indicated that the occurrence of naturally radioactive elements in fossil fuels—radium and its associated decay products—may represent as much of a hazard as the airborne effluents discharged from a nuclear plant. As yet, these effects have not been fully evaluated.

Except for thermal pollution effects which I will discuss later, current reactor technology and liquid waste control procedures indicate that the effects of radioactivity in the environment from nuclear power plant operations will be minimal. However, the possibility of the gradual accumulation of small amounts of radioactive materials by shellfish and other marine life where nuclear plants are located in the vicinity of coastal and tidal areas should not be ignored.

Another factor which merits consideration in the growing interest toward construction of nuclear plants in the Pacific Northwest, is the potential need for additional chemical reprocessing plants for handling the depleted reactor fuel. It is probable that one or more such plants will ultimately be required if the present plans for multi-nuclear power units are fulfilled. Thus, consideration must be given to the potential environmental effects of such plants and their location as an integral part of long-range planning and site selection for nuclear plants.

It might be interesting to note here that the comparative environmental effects of fossile versus nuclear plants are currently being studied in the Miami, Florida area where two nuclear plants will be built adjacent to two new fossile fuel plants of similar capacity. The results of this study will be of particular interest to this group and should provide further insight into the unanswered questions on environmental effects.

Thermal pollution of water

Another area of current concern is that of thermal effects on receiving streams from the discharge of condenser water from generating plants, both fossile and nuclear types. In some quarters there has been a tendency to minimize importance of this problem. In others, certain benefits of increased water temperatures such as in the growth of agricultural products and in the improved efficiency of water purification processes, have been mentioned.

Actually, thermal pollution of waterways can produce a variety of adverse effects, particularly from the standpoint of aquatic life. The quantity of oxygen that can be dissolved in water decreases as water temperatures increase. Conversely, the growth of biological organisms is stimulated by such increases. Thus, an increase in water temperature can not only bring about adverse effects on fish life, but also major changes in the entire aquatic ecological system as well.

Thermal pollution resulting from condenser discharges not only may be selectively detrimental to certain classes of stream biota, such as salmonid fish, but also may have adverse effects of significance to the human population. Warmer waters, for example, provide a more suitable environment for the growth of some less desirable species of aquatic life. These forms, such as filamentous and blue-green algae, can render some waters less suitable for use as public or industrial supplies in that they can impart objectionable tastes or ordors to the water and also increase the operational cost of water treatment plants. Also, some of these aquatic species can become a nuisance in the recreational use of public streams for water-contact sports.

More significantly, from the standpoint of human health, thermal discharges into marine waters may create health hazards as a result of the ingestion of shellfish harvested from such waters. Recent measurements taken in Puget Sound, for example, indicate that during the summer a temperature increase as small as 1° F. can "trigger" a rapid increase in the growth of plankton organisms which are toxic to humans. Further, pathogenic organisms such as Clostridium botulinum are more abundant on the estuarine mud flats of the Pacific Northwest. The growth of these and other organisms in clams and oysters in the marine environment has not been fully determined and, therefore, remains as a cause for concern.

Even in the most efficient modern fuel-burning power stations, about half of the heat produced during combustion is wasted and usually is discharged as heated condenser water into adjacent waterways. Although such effluents from single plants on the Columbia River may raise the water temperature only a fraction of a degree, the cumulative effects of a number of plants may raise the natural temperatures by several degrees. Clearly, means for reducing the thermal discharges to waterways must be incorporated into the planning and construction of new, large-scale power plants of the 1,000 megawatt range proposed.

The use of cooling towers, holding ponds, or other means may be practical alternatives toward reducing the thermal pollution load. These techniques provide cooling by evaporation of a portion of the water and thus deplete streamflow, which may be significant at some plant locations. Where streamflow is near critically low levels, the use of cooling towers may not be practicable. In general, however, water losses are relatively small and the use of cooling towers or holding ponds is preferable to continued discharge of undissipated waste heat into waterways in most locations.

The protective zoning concept

In considering site requirements, an analogy can be drawn with the often unchecked urban development which has encroached upon the once open areas surrounding many major metropolitan airports. The resulting problems of noise, nuisance, and potential accident hazard to the resident population, serve to illustrate the need for greater foresight to avoid similar encroachment near new power plants. Although both nuclear and conventional thermal power plants have among the best industrial safety records in the United States, the increasing size of new plants, dictated by economies of scale, suggest that greater and more sophisticated evaluation of present siting requirements and projected land use are becoming more important than ever before.

Thus, a concept of "protective or preventing zoning," in the form of "perpetual care"-type master plans is vital to minimizing adverse effects to public health. For example, the effects of abnormal operation of plants in the 1,000 megawatt range can be minimized by assigning low population density uses to the environs of these plant sites in the form of forest or wildlife preserves, golf courses, state or local parks, or other low-use zones. In the event of a sudden emergency, this would assure the mobility of the population and would not deprive a number of persons from their homes or places of work. This fundamental philosophy would also serve to minimize claims for alleged damages to health or property which might be attributed to power plant operations. As a further consideration, single plant stations may require subsequent enlargement and increased space to meet system load requirements.

Conclusion

In concluding my presentation I would urge that you continue the vigorous start you have made in long-range planning to meet the power generation needs so vital to the continued economic development and well-being of the people of the Pacific Northwest. The assistance of health agencies, Federal and State, is available to work with you to help minimize the health effects associated with thermal power development in this region. Their technical staffs can provide valuable suggestions on alternative means for accomplishing the overall objectives with minimal insult to the environment of man.

In the broadest view, the goal in power planning should be the same as that so ably expressed in a 1962 Senate Policy Document (No. 97): "Well-being of all of the people shall be the overriding determinant in considering the best use of water and related land resources. Hardship and basic needs of particular groups within the general public shall be of concern, but care shall be taken to avoid resource use and development for the benefit of a few or the disadvantage of many. In particular, policy requirements and guides established by the Congress and aimed at assuring that the use of natural resources, including water resources, safeguard the interests of all of our people shall be observed."

MATERIAL PREPARED BY THE PUBLIC HEALTH SERVICE

Public Health Factors in Reactor Site Selection

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Abstract.—The public health factors relating to the siting and operation of nuclear power plants in the United States are discussed. These factors include the land, air, and water environment as affected by the release of radioactivity, the relationship of siting to zoning practices, the thermal pollution problem, environmental surveillance, and protective action planning. The problems of multiple reactor sites, areas having a number of reactor sites, and regional groups of nuclear plant complexes are presented. The responsibilities of the National Center for Radiological Health and of State and local health authorities in assuring public health protection and planning for the continued growth of nuclear power are discussed. Further, the planning and assessment role of health agencies with regard to the major urban facilities and policies as these effect nuclear facility site selection is presented.

INTRODUCTION

The development of nuclear power in the United States has periodically been reported to the public by the nuclear industry and by the U.S. Atomic Energy Commission (AEC). These reports indicate that nuclear power plants have apparently become competitive with fossil fuel plants in many geographical areas (1, 2). Recognition of this fact and the overall expanded United States electrical power requirements have resulted in a substantial increase in the number of nuclear power plant orders by both private and public utilities. In mid-1967, the U.S. Atomic Energy Commission revised its previous forecast on installed nuclear capacity upward by 50 percent. The Commission now estimates that between 120,000 and 170,000 megawatts of electricity will be generated using nuclear power by the year 1980 (3). Figure 1 shows the projected growth of nuclear power as compared to other sources of electrical energy generation.

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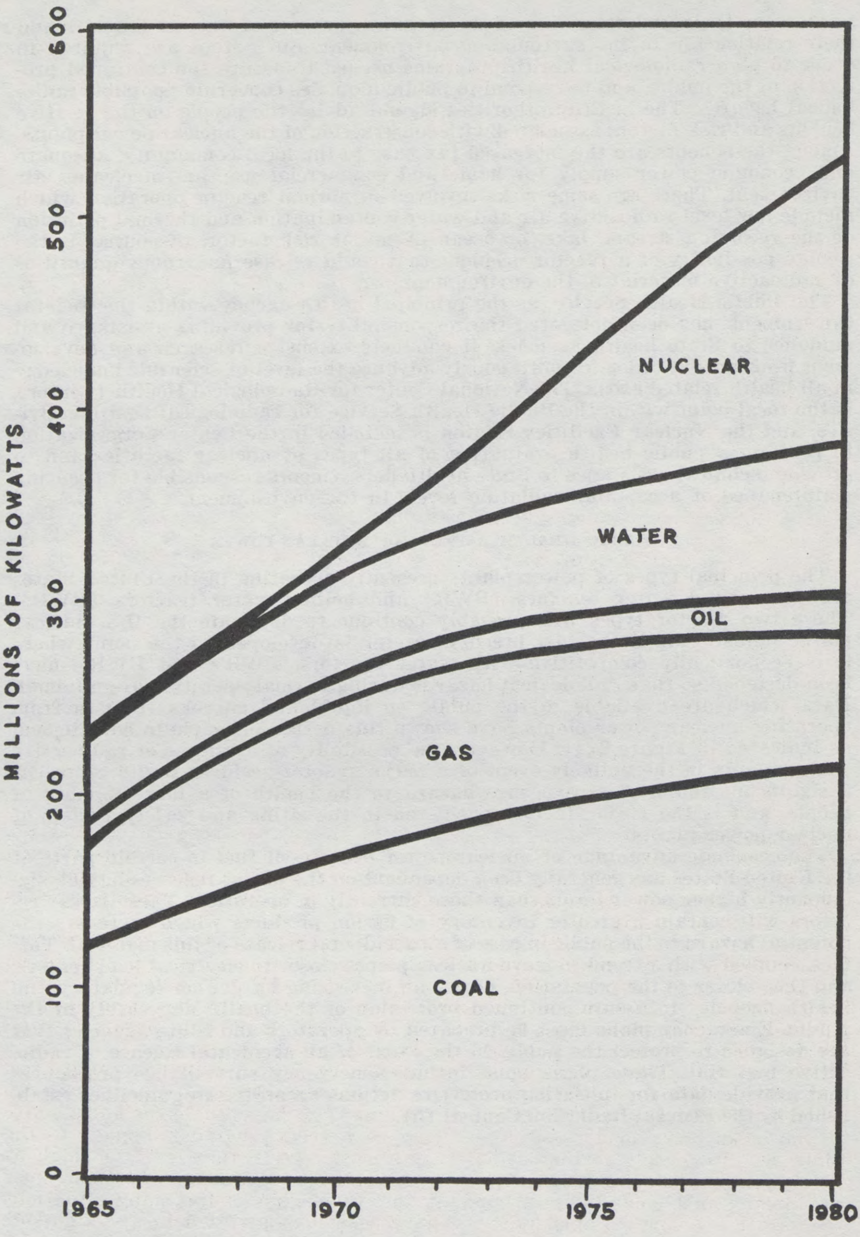

FIGURE 1.—Projected energy sources for electric power.[3]

In the United States, the Atomic Energy Commission has the authority and responsibility for licensing and regulation of nuclear power plants. The Commission's reactor licensing procedure includes a comprehensive safety evaluation of the design features and operating characteristics needed to assure safe operation of these plants. Because State and other Federal agencies also have responsibilities for public health protection in the United States it is necessary for them

[3] The nuclear industry, 1967.

to increase their understanding of the technical aspects of nuclear reactors and their relationship to the surrounding environment. Such steps are required in order to plan radiological health programs needed to assure the continued protection of the public, and to respond to public inquiries concerning possible radiological hazards. The health authorities should advise the people on the relative benefits and risk factors associated with construction of the nuclear power plants. Among the benefits are the increased tax base to the local community, adequate and economic power supply for home and commercial use, and a cleaner air environment. There are some risks involved in normal reactor operation which include low-level radioactive air and water contamination and thermal pollution of the receiving stream, lake, or ocean. A major risk factor, of course, is the remote possibility of a reactor accident that could release hazardous quantities of radioactive material to the environment.

The Public Health Service, as the principal health agency within the Federal Government, has been delegated the responsibility for providing assistance and guidance to State health agencies. It conducts extensive research and development programs in order to continuously advance the level of scientific knowledge in all health related areas. The National Center for Radiological Health (Center) is the focal point within the Public Health Service for radiological health activities, and the Nuclear Facilities Section is included in the Center's organization to perform a public health evaluation of all types of nuclear facilities and to provide technical assistance to State health departments responsible for assuring maintenance of acceptable radiation levels in the environment.

PUBLIC HEALTH ASPECTS OF NUCLEAR POWER

The principal types of power plants presently operating in the United States are pressurized water reactors (PWR) and boiling water reactors (BWR). These two reactor types will probably continue to dominate the U.S. nuclear power industry until the fast breeder reactor is developed to the point where it is economically competitive with water reactors. PWR's and BWR's have been designed so that radiological hazards during normal operation are minimal. Data which are available to the public on liquid and gaseous releases from operating nuclear power plants have shown this design principle to be satisfied, as indicated in Figure 2(4). However, the possibility of a release of radioactive contaminants in the unlikely event of a major reactor accident would represent a significant radiological exposure hazard to the health of a large number of people, and is the major factor considered in the siting and safety review of nuclear power plants.

The economic advantage of nuclear power over fossil fuel in certain parts of the United States has generally been dependent on the use of reactors having significantly higher power levels than those currently in operation. These larger reactors will contain a greater inventory of fission products which increases the potential hazard to the public in case of an accidental release of this material. This fact, coupled with a trend to move nuclear plants closer to electrical load centers, and thus closer to the population, places an increasing burden on regulatory and health agencies to assure continued protection of the health and safety of the public. Emergency plans must be prepared by operators and State agencies that are designed to protect the public in the event of an accidental release of radioactive material. These plans must include emergency surveillance procedures that provide data for initiating protective actions according to guidelines established by the Federal Radiation Council (5).

FIG. 2.—LIQUID AND GASEOUS WASTE RELEASES AT CURRENTLY OPERATING POWER REACTORS

[BWR: Boiling water reactor; PWR: Pressurized water reactor]

Reactor	Years of reactor operation	Type	Range of average liquid waste concentrations after dilution with condenser cooling water, percent of limit		Range of average gaseous waste releases, percent of limit [1]	
			Gross beta activity [2]	Tritium activity [3]	Activation and noble gases	Halogens and particulates
Yankee: Rowe, Mass	7	PWR	[4] 0.001–0.013	0.16	0.001–0.03	([5])
Indian Point: Buchanan, N.Y	5	PWR	[4] 0.03–4.7	0.03	0.00013–0.0026	$<10^{-6}$
Dresden: Morris, Ill	8	BWR	[6] 0.3–3.8	$<10^{-3}$	<0.02–3.6	([5])
Big Rock Point: Charlevoix County, Mich	5	BWR	[4] 1.9–9.9	0.007	<0.002–3.5	<30
Humboldt Bay: Eureka, Calif	4	BWR	[4] 0.3–1.2	0.0035	0.08–28	1–38
Elk River: Elk River, Minn	5	BWR	[4] 0.0002–0.05	0.006	0–18.0	<1

[1] Gaseous discharge limits are stated in the operating license for each facility.
[2] Not including tritium.
[3] Limit is based on a continuous discharge of tritium (averaged over 12 consecutive months) of 3×10^{-3} μCi/ml.
[4] Limit is based on a continuous discharge (averaged over 12 consecutive months) of 10^{-6} μCi/ml of unidentified isotopes of plant origin.
[5] Not available.
[6] Limit is based on a continuous discharge (averaged over 12 consecutive months) of $10^{-6}\mu$Ci/ml of activity, including natural background in river water.

The large increase in nuclear power plant orders has also resulted in plans for placing more than one reactor at several existing and future sites. A number of reactor sites are planned to be sufficiently close together so that all will share the same air and water environment. This trend could create an environmental problem potentially significant from an area, regional, and even national standpoint, particularly when the concurrent growth of the nuclear fuel reprocessing plants required to handle the spent reactor fuel from these plants is considered (6). For this reason, both the Center and State environmental surveillance activities will ultimately have to provide for evaluation of environmental radioactivity over relatively large geographical areas.

REACTOR OPERATING EXPERIENCE

In the United States, to date, there have been no boiling water reactor or pressurized water reactor incidents in which releases of radioactivity to the environment have exceeded the population exposure guides set forth in the Atomic Energy Commission regulations. Over eighty United States nuclear submarines with PWR's have been constructed and operated with no significant nuclear-related incidents. In order to achieve this excellent record, the United States Naval Reactors Program developed rigid design and quality control specifications and procedures which have had considerable influence in the design and construction of both types of commercial light water power reactors. The United States reactor industry as a whole has experienced malfunctions or failure in parts such as valves, fittings, piping, and pumps which have resulted in a temporary shutdown of the facility, but have not caused significant personnel overexposure or radiation release to the environment.

Without exception, all serious reactor incidents experienced thus far have occurred at prototype, test, or production reactors. In most cases, the incidents were a direct result of deliberate bypassing of the safety system or operating the reactor under extraordinary test conditions where the potential for a controlled incident was realized beforehand. The current generation of PWR's and BWR's cannot be placed in the same class as prototype and test reactors when predicting incident potential. A higher incident rate would be expected at the prototype and test reactor facilities.

Power reactors for commercial use are currently designed to include inherent and engineered safeguards systems which help to prevent incidents and which minimize their consequences, should they occur. Since the effectiveness and reliability of the engineered safeguard systems have not been fully demonstrated under actual plant operating conditions, it is not possible to accurately evaluate their impact in reactor siting. Plans and facilities are being developed by the Atomic Energy Commission to test and evaluate several systems. These include the Nuclear Safety Pilot Plant at Oak Ridge, Tennessee, the Loss of Fluid Tests at Idaho Falls, Idaho, and the Containment Systems Experiment at Hanford, Washington (7, 8).

PUBLIC HEALTH FACTORS IN REACTOR SITE SELECTION

The principal objective of a siting study is to determine the advantages and disadvantages of several potential locations and to subsequently select the most advantageous location for a nuclear power plant. The factors that must be considered are economic as well as safety and include those of interest to State and local governmental agencies. It is important that the State health agency and the power company establish a working relationship during the planning stage of a nuclear power plant. The health agency, together with other State and local agencies having official interests in the siting of nuclear plants (agriculture, conservation, water resources, zoning boards) can assist the utility company's planning staff by providing pertinent information and guidance on laws, regulations, and health considerations that may affect the proposed plant. At least one State has established a power plant site evaluation committee made up of representatives from several concerned State agencies (9). This committee reviews sites proposed by the utility companies for power plants and gives its opinion as to their suitability from the State's viewpoint.

Studies of potential power reactor sites on a region-wide basis show considerable promise as a means for identifying possible sites for future development. Such a regional study has been conducted for the Pacific Northwest area of the United States (10). The advantages and disadvantages of many sites can be evaluated and those found most suitable from health, conservation, and economic standpoints, identified and possibly reserved for future use.

One of the areas where the State and local governments can play an important role in cooperation with the utility company is in planning for maintaining the acceptability of a site for its intended purpose. During the initial evaluation of a reactor site, a certain exclusion distance is established and the population centers and their distances from the site are factored into the evaluation. During the lifetime of the plant, changes in the environs may take place by population encroachments which could make the original safety evaluation invalid. Certain zoning restrictions may therefore be required to prevent unacceptable population, commercial, or industrial growth in proximity to the plant. An analogy to the power reactor zoning problem has occurred in recent years in airport site selection (11). Increased air transportation has caused a trend toward industrial location in the vicinity of major airports. This industrial trend has led to development of housing projects near the airports. Problems of noise, nuisance, and potential accident hazard to the resident population have resulted even though the airport was initially located in an isolated area. Thus, it has been demonstrated, in many cases, that there exists a need for more sophisticated evaluation of airport siting requirements and land usage around these facilities. The nuclear industry should take cognizance of this example in their advance planning for reactor plant facilities in order to avoid similar zoning problems.

Preferred land uses for reactor plant environs would be recreational, wildlife refuges, military establishment, or other uses where the population can be moved rapidly with a minimum of economic loss. For example, the development of the 2900 acre site for the Turkey Point reactor of the Florida Power and Light Company demonstrates restricted land usage combined with a public education and relations program. The company has located a Boy Scout and a Girl Scout camp, an Air Force sea survival school, a shrimp breeding research station, and a beach and picnic area on the reactor site. Most of the site which has not been used by the facilities mentioned above, has been designated as a wildlife refuge.

Figure 3 lists several factors which must be considered in evaluating the suitability of a reactor site. Although all of the considerations listed are of interest to health agencies, certain ones are more important from a health standpoint. Physical and environmental factors will be individually discussed in the following paragraphs.

Geology and seismology.—These factors are of particular importance in the assessment of site suitability. The subsurface foundation materials must meet the high load-bearing requirements imposed by the reactor complex to insure stability. In addition, special considerations must be given to seismic activity in the site vicinity. This factor has been most significant in reactor siting in the Western part of the United States and was the principal factor for the withdrawal of one nuclear power plant application (12) and in the delay of one other application (13).

FIGURE 3.—**Factors to be considered in reactor site selection**

Physical factors:
- Seismology
- Geology
- Topography
- Meteorology
- Hydrology

Environmental health factors:
- Radioactive air contamination
- Radioactive water contamination
- Radioactive land contamination
- Radioactive food contamination
- Thermal pollution
- Land use

Demographic factors:
- Population density
- Population mobility

Meteorology.—Meteorological factors should be evaluated at the reactor site in order to determine the suitability of the plant environment to receive radioactive discharges under accidental as well as normal operating conditions. The objectives to be accomplished in a site meteorological analysis are to: (1) determine local weather characteristics which influence the transport and dilution of airborne radioactivity; (2) statistically describe the occurrence of certain weather phenomena; and (3) identify irregularities in weather or meteorologic behavior. The average yearly meteorologic conditions are normally used for calculating dispersion and concentration of operational waste releases whereas the worst case conditions are used to define the predicted meteorological dispersion regime following an accident.

Hydrology.—An extensive review of pertinent hydrologic data is a necessity in site selection. The adequacy of the water supply must be evaluated in view of both the condenser cooling water and radioactive waste dilution requirements. High water data must be considered to insure that critical components of the plant will not be adversely affected during a flood. Ground water levels and movement should also be considered in light of the unlikely but possible contamination of drinking water taken from nearby wells. In selection of the site, the present and the planned future use of any plant surface water supply should be studied. The effect of transport of radioactivity through the aquatic environment upon present and future surface water uses, such as public water supplies and industrial, irrigational, and recreational applications, should be determined. For example, development of dams on a river, or extensive irrigation, could substantially alter the site hydrologic characteristics and adversely affect site desirability.

Radioactive air contamination.—Gaseous fission products are found in the primary coolant of a reactor as a result of leakage and diffusion through the fuel cladding and fissionable contaminants on the outside of the fuel elements. These radioactive gases, present in the air effluent, result from the operation of relief valves, air ejectors, and other mechanisms. Low-level airborne radioactivity can be released and diluted in the atmosphere whereas higher level radioactivity is treated by one of the methods shown in Figure 4. To hasten the dilution and dispersion of both treated and untreated contamination into the atmosphere, it is released from a nuclear reactor via a stack or an exhaust duct on the top of the containment structure. It should be noted that increasing the flow rate of air discharged from the stack will lower the discharge concentration, but will not effect the total quantity of radioactive material discharged to the environment or the resultant exposure of the population in the vicinity of the site.

Radioactivity released to the atmosphere during normal reactor operation can cause exposure to humans either by ingestion or by direct inhalation. The deposition-ingestion chain occurs when airborne radioactivity is deposited on soil or plant tissue, where it is adsorbed or metabolized through plants and becomes available for animal or human consumption. Doses to the population via the iodine deposition-milk-food chain can be calculated to be the factor limiting gaseous radioactivity discharges from reactor plants during normal reactor operation. However, results of environmental surveillance programs around operating power reactors have not shown iodine deposition and concentration in milk to be a problem (4).

FIGURE 4.—Treatment methods for contaminated gaseous effluents from reactors

Storage or temporary retention to allow decay of relatively short-lived isotopes.
Filtration to remove particulate activity.

The population exposure from radioactive emissions under reactor accident conditions are naturally of greater concern than those exposures that may occur from normal operations. Accident exposure may result from ingestion, direct inhalation, and gamma radiation exposure during passage of the radioactive cloud. The reactor site boundary and the distances from reactor sites to surrounding towns and cities are utilized in calculating inhalation and direct gamma radiation doses, from a postulated accident release, which are compared against siting criteria published by the Atomic Energy Commission (14, 15). Population exposure via the deposition and food ingestion pathway during an accident is not used as a criterion in siting United States power reactors since protective actions can partially reduce or eliminate this critical exposure pathway.

Radioactive water contamination.—As in the case of radioactive releases to the atmosphere, data available to the public from operating nuclear power plants has shown that careful waste management practices, good monitoring techniques, and proper operating procedures result in a minimal release of radioactivity to the water environment (4, 16). Low-level liquid wastes are usually released directly to the condenser cooling water discharge canal where they are diluted to acceptable environmental levels with the condenser cooling water. Provisions are made for treatment of high and intermediate level liquid wastes by one or more of the methods shown in Figure 5.

FIGURE 5.—Treatment methods for contaminated liquid effluents from reactors

Storage to allow decay of relatively short-lived isotopes.
Filtration to remove particulate activity.
Ion-exchange or demineralization to remove dissolved activity.
Distillation to reduce the volume of wastes to be stored.

The reactor plant is the last point of absolute control of the concentration of the liquid radioactive contaminants. After the contaminants have been released from the plant, the principal human exposure pathways are from drinking water and from consumption of food. The principal factors to be considered in controlling population exposure from drinking water are shown in Figure 6.

FIGURE 6.—Factors controlling population exposure from drinking water

Minimum Travel Time to Water Intake—determines time available after a release to discontinue water intake at a plant.

Water Plant Storage Capacity and Population Usage Rate—determines the length of time water intake may be stopped.

Water Plant Contamination Removal Efficiency—determines amount of contamination which can be removed before consumption.

Decay Time During Treatment and Storage—accounts for radioactive decay during water treatment and storage before use.

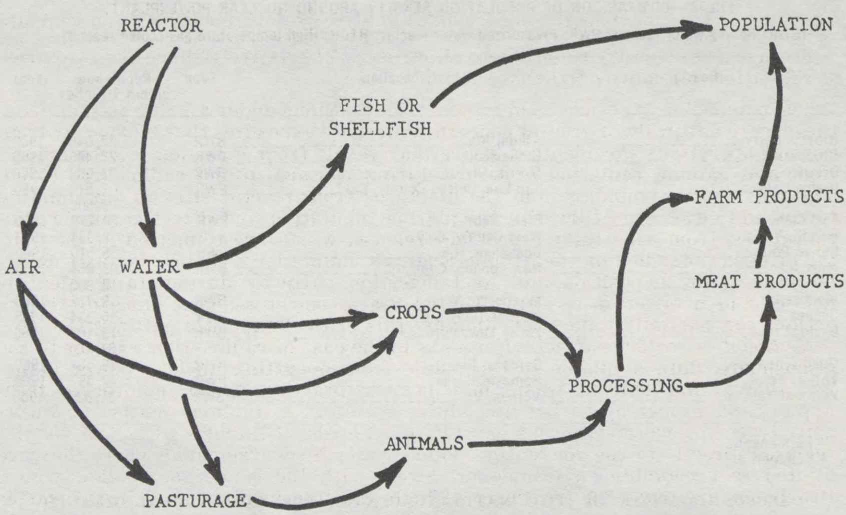

FIGURE 7.—Exposure pathways through the human food chain.

Food contamination results from reconcentration of radioactivity in edible fish or shellfish or through agricultural use of contaminated water for irrigation purposes. A possible additional exposure pathway following a reactor accident is by recreational use of contaminated water. If this is of concern, water contamination should be checked by competent health authorities before recreational activities are allowed to proceed.

Radioactive land contamination.—As has been indicated above, radioactive contamination of land usually occurs via deposition of airborne contaminants or through use of contaminated water for crop irrigation. The methods for transfer of radioactive land contamination through the human food chain are given in Figure 7.

Land contamination can create a more serious long-term exposure problem than radioactivity present in air or water because very little dispersion or movement occurs following deposition and fixation in the soil. Thus, a siting study should also include an evaluation of the effects of possible radioactive land contamination upon the present and projected future land use in the area surrounding the site.

Population density.—Population density is an important factor to consider in selecting optimum reactor sites in relation to protective action planning by utility companies and State health agencies. Based on data available to the public, release rates of radioactive air and water contaminants from power reactors during normal operation has been quite low. However, in the unlikely event of a reactor accident, relatively large quantities of radioactive materials could be released to the environment. This necessitates locating reactors in areas with low population densities or close to populations of high mobility who could be moved in a short time period. Figure 8 shows population densities within ten miles of reactors currently operating and under construction.

FIG. 8.—COMPARISON OF POPULATION SENSITY AROUND NUCLEAR POWERPLANTS

[BWR: Boiling water reactor; PWR: Pressurized water reactor; HTCR: High temperature gas-cooled reactor]

Reactor	Location	Type	Population within 10 miles	Year
Browns Ferry	Athen, Ala	BWR	22,040	1960
Brookwood	Brookwood, N.Y	PWR	27,480	1965
Dresden	Morris, Ill	BWR	22,600	1960
Diablo Canyon	San Luis Obispo County, Calif	PWR	[1] 1,570	1960
			[2] 3,500	
Fort Calhoun	Blair, Nebr	PWR	24,270	1960
Fort St. Vrain	Weld County, Colo	HTGR	8,384	1960
Indian Point	Buchanan, N.Y	PWR	155,510	1960
Millstone	New London, Conn	BWR	[1] 95,864	1960
			[2] 118,000	
Monticello	Monticello, Minn	BWR	9,712	1960
Oconee	Keowee Dam, S.C	PWR	36,334	1965
Oyster Creek	Lacey Township, N.J	BWR	[1] 13,108	1960
			[2] 64,200	
Quad Cities	Cardova, Ill	BWR	39,488	1960
Turkey Point	Homestead, Fla	PWR	42,397	1966
Vermont Yankee	Vernon, Vt	BWR	31,038	1960

[1] Permanent.
[2] Summer.

RESPONSIBILITIES OF THE NATIONAL CENTER FOR RADIOLOGICAL HEALTH

Under a 1961 agreement, the Atomic Energy Commission's Division of Reactor Licensing provides the Center with copies of the design safety analysis reports submitted by applicants proposing to build and operate nuclear power plants. These reports are provided to the Public Health Service for their use in assessing releases of radioactive contaminants to the environment.

The Center's Nuclear Facilities Section reviews reactor design and analysis reports and prepares a report which includes, among other factors, an evaluation of site suitability, plans for environmental surveillance, methods for processing liquid and gaseous radioactivity, and protective action planning. Particular attention is given to the design and operation of the environmental surveillance programs in the area surrounding the facility. Calculations are also made of possible radiation dose to children as a result of consuming milk containing radionuclides resulting from a postulated release of fission products from the facility. The public health evaluation is based upon a site survey by the responsible Center representative and on specific factors, presented by the applicant for the nuclear facility, which are of interest to public health agencies. These include iodine releases under accident conditions, meteorology, population mobility, water supplies, industrial development, and agriculture usages.

The principal use for these public health evaluation reports is to provide specific recommendations and guidance to State health agencies who have responsibilities for assuring that radioactive contaminants in the environment are maintained at a minimum level. The report serves as a useful reference for establishing those aspects of the proposed facility about which State personnel should be knowledgeable. It also assists them in fulfilling their role of providing information to the people within the State on the health aspects of the facility, establishing the advantages and disadvantages for operation of the facility at the proposed reactor site, and in developing protective action plans. The health commissioner or governor may also use the public health report as an input in their participation in the Atomic Energy Commission's regulatory process. The Atomic Energy Commission's licensing procedure requires a public hearing at the construction permit stage. The State is encouraged to appear at these hearings in order to present its views on the public health aspects of the proposed facility and to make a statement for the record.

The Nuclear Facilities Section, in carrying out their responsibilities, coordinates its activities with other Federal Government agencies on matters pertaining to reactor safety and discharge of radioactive contaminants to the environment. These agencies include the Atomic Energy Commission, the National Center for Air Pollution Control, the National Center for Urban and Industrial Health, the Federal Water Pollution Control Administration, the Food and Drug Administration, and the Environmental Science Services Administration. Upon request, technical reports are provided to Congress or Congressional Committees, such as the Joint Committee on Atomic Energy.

A continuing review of the reactor facility is conducted by the Center until the final safety analysis report is submitted, whereupon a final evaluation is made of the projected public health aspects prior to start up of the reactor. This report summarizes the changes that have been made in the reactor design and operation to assure that the reactor can be operated without undue continuing exposure under normal operating conditions and with a minimum exposure should an accidental release of radioactivity occur.

EVALUATION OF ENVIRONMENTAL RADIOACTIVITY FROM NUCLEAR FACILITIES

The increased demand for nuclear power as a means for generating electrical power has resulted in both State and Federal public health agencies increasing their radiological health program efforts related to power plants and other nuclear facilities. To illustrate the magnitude of the problem facing these agencies, Figure 9 shows the number of nuclear power plant construction applications received by the Atomic Energy Commission during the period 1963–1967.

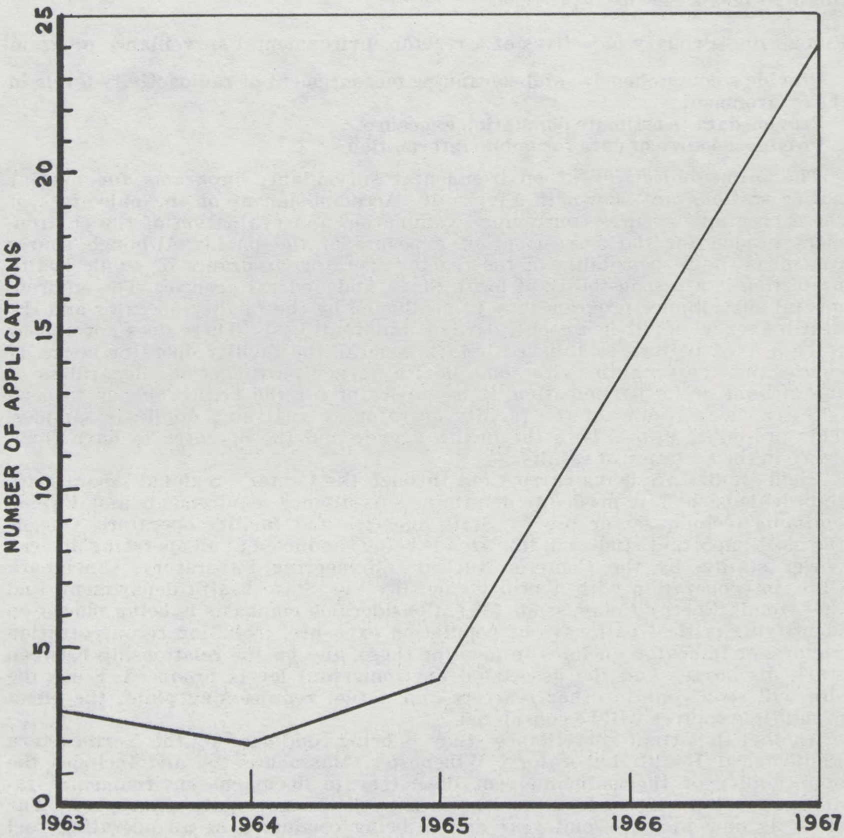

FIGURE 9.—Number of power reactor applications by year.

The Center conducts an environmental surveillance program which includes a comprehensive, continuing measurement of radio-activity levels in the environment by means of several national surveillance networks (17). Information from these networks is used to estimate public exposure and doses relatable to environmental radioactivity. The surveillance system is designed to be responsive to changes in radioactivity levels in the environment. The current surveillance activities include the collection and analysis of airborne particulates, water, milk, total diets, bovine thyroid glands, human bones and organs, and special samples relating to human body burdens and doses. Many States operate similar statewide networks that are coordinated with the Center network system.

In addition, environmental surveillance programs are conducted in the vicinity of operating nuclear facilities by the operator and health agencies. With such a system of National, State, and facility surveillance programs in operation, the long-term trends of environmental radioactivity resulting from the nuclear power industry can be well documented. In addition, special surveillance systems have been established which can be activated in the event of a reactor accident and will indicate whether levels of radio-active contaminants exceed Federal Radiation Council guidelines for protective action to control population exposure (5).

In its traditional role of providing technical assistance and consultation to State health agencies, the experience of many agencies and groups have been utilized by the Center in developing recommended guides for environmental surveillance around nuclear power plants (18). In order to assure compatability of the surveillance data from both Federal and State programs, and Analytical Quality Control Service is provided.

FIGURE 10.—Primary objectives of a reactor environmental surveillance program

Provide a comprehensive and continuing measurement of radioactivity levels in the environment.

Provide data to estimate population exposure.

Provide a source of data for public information.

The prime objectives of environmental surveillance programs for nuclear power stations are shown in Figure 10. Accomplishment of the objectives of these programs assures continuing examination and evaluation of the environment needed for the assessment of exposure of the public. Although source control is the responsibility of the reactor operator, assurance of public health protection is a responsibility of local, State, and Federal agencies. The environmental surveillance program may be conducted by the facility operator and the health agency on either a cooperative or unilateral basis. There does not appear to be a fixed pattern established but, in general, the facility operator normally carries out the program with some health agency participation. Regardless of the amount of its participation, it is important for the health agency to periodically check results of the facility operator by analyzing duplicate samples. This procedure allows both the health agency and the operator to have confidence in the accuracy of results.

Field studies are being carried out through the Center's regional laboratories to provide basic data needed to determine surveillance requirements and develop optimum techniques for use by State agencies and facility operators. One of the most important studies in this area is being conducted at an operating nuclear power station by the Center's Nuclear Engineering Laboratory, Cincinnati, Ohio, in cooperation with a utility company, the State health department, and the Atomic Energy Commission (19). Considerable emphasis is being placed on identifying critical pathways of population exposure, including reconcentration factors, or indicator nuclides to monitor these, and on the relationship between stack discharges and the associated environmental levels produced. Since the site will soon contain other reactors and a fuel reprocessing plant, the effect of multiple sources will be considered.

Another important surveillance study is being conducted by the Northeastern Radiological Health Laboratory, Winchester, Massachusetts, and includes the applicability of thermoluminescent dosimetry to document environmental radiation levels resulting from nuclear facility discharges to the atmosphere. The study is now in its second year and is being conducted at an operating fuel reprocessing plant. Such a plant was chosen as the best facility for this study since releases of noble gases, especially ^{85}Kr, are greater than those from a nuclear reactor.

In its program activities concerning environmental surveillance around nuclear facilities, current and past power reactor surveillance program experience is being utilized. Reported data from all operating power reactors are being compiled in order to assess the long-range environmental effects of the nuclear power industry in the United States. In order to assess these effects, a readily accessible record of discharges of radioactivity from nuclear facilities and the observed environmental levels related to these discharges is needed.

An automatic data processing system is being used for retrieval of information in several formats that will be of use to State and local health agencies, other

Federal agencies, and the nuclear industry. When fully operable, this system will provide a means for evaluating the performance of environmental monitoring programs and determining trends of environmental radioactivity from nuclear facilities on a national, regional, and area basis.

Within the Public Health Service, the National Center for Air Pollution Control, under the authority of the Air Quality Act of 1967 (20), has the regulatory responsibility for air pollution control. The National Center for Radiological Health is responsible for advising the National Center for Air Pollution Control regarding radiological contamination control of pollutants in the atmosphere. Fossil fueled power plants emit large quantities of conventional air pollutants such as the oxides of nitrogen, carbon, and sulfur which are not present in the gaseous effluent of nuclear reactors. There have been articles in the literature that indicate that some types of fossil fuel plants may also emit more hazardous quantities of radioactive materials than nuclear plants operating under routine conditions (21). The Center is currently conducting a research project to obtain such data that will help clarify the radioactive air pollution characteristics of conventional and nuclear plants (22). The data collected may also be used to determine the relative health effects on the population residing in the vicinity of the plants.

Another factor which some health agencies must consider in comparing nuclear and fossil fueled power plants is the discharge of the heated water to the receiving water bodies adjacent to the facility. The fossil fuel plants currently have a thermal efficiency of about 36 percent as compared to an efficiency for nuclear plants of about 25 percent. This results in a somewhat higher thermal load being placed on the receiving stream from a nuclear plant for a given electrical generating capacity (23).

PROTECTIVE ACTION PLANNING

Public health programs involving the nuclear power industry must provide for protective action plans for uncontrolled releases of radioactivity whether from a small incident or a major accident. Failure to develop adequate plans could result in unnecessary risk to the public. Thus, there is a very practical reason for the public health agency and the utility company to work jointly to develop plans to detect, evaluate, and resolve the consequences of a full spectrum of uncontrolled releases of radioactivity to the environment.

The health agency, in preparing plans, should evaluate the resources available for responding to an emergency, including police, radiation monitoring capabilities, communications, medical facilities, transportation, and radiological laboratory capabilities. Detailed plans, as agreed upon by the State and utility company, should contain: (1) a clear understanding of responsibility and authority to act in the event of an accident; (2) criteria that require notification of health and regulatory agencies; (3) a list of personnel to be contacted and telephone numbers; (4) provision for sufficient instrumentation, both on-site and off-site, to detect an emergency condition quickly and to determine the extent of contamination; (5) protective actions to limit the spread of contamination and minimize the radiation dose delivered to the public; (6) procedures for decontamination and movement of injured people and adequate medical care; (7) means of determining if evacuation of the public is required and, if so, how this will be carried out; (8) periodic tests of monitoring systems to determine if they will function under accident conditions; and (9) periodic testing of the plan to assure up-to-date competence in its execution. It is also advisable to obtain sufficient written agreement on the plan to make it binding on the parties involved.

Among the major reasons for protective action planning are those presented in Figure 11. Each of these reasons concerns the State health agency. In the event of release of radioactive contaminants to the off-site environ, it is the responsibility of the State health agency, with the advice of the Public Health Service, the Atomic Energy Commission, and the utility company, to assess the impact on the public and take necessary actions to protect their health by reducing radiation exposure. If it becomes necessary to divert or condemn milk supplies due to radioiodine contamination, the State's action may be on the basis of advice from the Public Health Service. The power company may be held liable for damages that occur, but their responsibility is economic. The State's responsibility can never be economic in a nuclear accident; it must be in the interest of the public health, safety, and welfare.

FIGURE 11.—Reasons for protective action planning at nuclear power reactors

Although the probability of an accident is low, the consequences could be severe.

The large number of power reactors presently being planned or built has increased the probability of incidents or accidents occurring.

A substantial increase in power levels results in a greater accumulation of fission products and, therefore, the potential hazard is becoming greater.

Economic factors in power distribution are tending to bring reactor sites in closer proximity to population centers with a resultant increase in the projected consequence of an accident.

Liaison should be established between the State and the utility company prior to start of construction and should continue throughout the plant's operation, One condition of granting the company a State permit to discharge wastes from the facility should be completion of an adequate plan to resolve off-site releases of radioactivity. The Center provides radiological assistance to States in planning for emergencies as well as providing laboratory support and technical personnel during an actual incident. In regard to reactors, the States are encouraged to have specific plans for each reactor in the State that can be integrated with an overall State radiological incident plan. Guidance is given on methods of evaluating the incident, protective actions that should be taken, and the basis for taking them. This role is important to provide uniformity in State emergency planning. An occasion when this becomes particularly important is when a reactor is located where an accident could release radioactivity into two or more States. In these situations interstate agreements are recommended to assure adequate protective action.

Another important aspect of emergency planning that a State should consider is the availability of resources to augment its own. In the United States, the Atomic Energy Commission makes available the resources of its laboratories and technical personnel, organized in assistance teams, in resolving nuclear accidents of any type. The Center has made similar commitments of its laboratories to participate with the Atomic Energy Commission in an Interagency Radiological Assistance Plan that includes other Federal agencies.

REACTOR LIABILITY INSURANCE

Liability claims resulting from an accident at a plant are always economic considerations when discussing industrial plant siting, and the nuclear power field is no exception. Under present law, the private insurance industry is expected to insure against liability loss from reactor accidents up to $60,000,000. As is true in other types of insurance liability coverage, the insurance rates for reactor liability insurance are usually based on site location, engineered safeguards systems incorporated into the plant design, and potential population dose in the unlikely event of an accident.

The Price-Anderson Indemnity Act (24) provides an additional $500,000,000 of Federally sponsored coverage. This insurance is supplied to the reactor owners at a relatively low cost and raises the total amount of liability coverage available to $560,000,000. The Act further relieves reactor owners of financial responsibility for claims in excess of $560,000,000.

The reasons for providing these high levels of insurance coverage in the United States are often questioned in light of the assertion that current nuclear power plant designs lead to a very low probability of occurrence of a serious accident. However, United States power reactors are presently being licensed as "research and development" facilities and this special insurance protection provides an extra margin of coverage for any health related exposures or effects that may occur in case of accidents.

CONCLUSIONS

Nuclear power generation has experienced a rapid growth during the past ten years and it is predicted by the Atomic Energy Commission and the nuclear industry that it will continue to expand. Economic factors in power distribution are tending to bring reactor sites in closer proximity to population centers with a resultant increase in the projected consequences of an accident. If these locations are to meet siting criteria, reactor manufacturers should be required to include engineered safeguards systems in their designs, which have been tested and proven.

The increased use of nuclear power makes it imperative that all levels of government concerned with the public health and safety increase their knowledge of the design and operating characteristics of nuclear plants. This will permit health personnel to effectively work with reactor manufacturers, operators, the Atomic Energy Commission regulatory program, and other interested government agencies to assure that a progressive development of this power source provides continuing protection of the public health and is compatible with preservation and enchancement of man's environment and with conservation of scenic, historic, recreational, and other natural resources.

Factors of specific concern to the National Center for Radiological Health of the Public Health Service and to State and local health agencies include reactor siting, environmental evaluation and surveillance of operating facilities, and protective action planning. The National Center for Radiological Health is presently cooperating with State and local health departments, the Atomic Energy Commission, and utilities to develop mutual competence in these areas. The Center believes that comprehensive regional studies should be made, which include physical and environmental factors, that would serve to identify and preserve potentially desirable reactor sites. These studies and evaluations should be undertaken as a cooperative effort by utility companies or power agencies in a region of interest. There should be full cooperation between these utilities and the Federal, State, and municipal government authorities responsibe for zoning, air and water pollution control, general public health, and conservation.

The Center is conducting research and development in several areas related to the radiological aspects of nuclear power production which affect public health and safety is available for consultation to States and other government agencies in any of the areas relating to radiological health.

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ARTICLES BY JOHN CAIRNS, JR.

[From Industrial Wastes, March–April 1956]

EFFECTS OF INCREASED TEMPERATURES ON AQUATIC ORGANISMS

(By John Cairns, Jr.)

Living things can withstand the effects of heat only within very narrow limits. Man is fortunate in having a rather elaborate and effective series of regulatory mechanisms, sweating for example, which enables him to keep his body temperature reasonably constant. But even man will die if his temperature is raised by about 10 degrees, as in the case of a high fever.

The fish and other aquatic organisms, lacking most of man's protective devices, are much more susceptible to the effects of increased heat in the environment. Some of them can move into cooler areas, but this is avoidance rather than regulation.

The temperature an aquatic animal can tolerate depends greatly upon the temperature of the normal environment. In general, the cooler the natural habitat the lower will be the maximum temperature that can be endured. As an example, tropical fish are adapted to warm waters that would kill a brook trout. Sometimes the margin of safety is very slight. The polyps that build coral reefs are killed at temperatures only two or three degrees above those at which they carry out a normal existence.

INDUSTRIAL THERMAL LOADINGS PRESENT AND FUTURE

The importance to industry of heat tolerance is obvious, since the largest single industrial use of water is for cooling purposes. Naturally, the heated water will raise the overall stream temperature if it is returned directly. In most cases present usage does not harm the streams, but enough cases of injury have developed to indicate that the problem exists now. One might think that danger from heat load would be confined to southern areas where natural stream temperatures are very high during the summer and only a relatively small additional heat load may kill fish. However, instances of over-heating have also come to attention in cooler streams of the northeastern states.

It is not the existing thermal loadings that are the main cause of concern, but those of the future. An outline of expected thermal loadings based on known processes and energy sources was given by Joseph R. Clark at a recent conference on a sewage and industrial wastes. The following paragraphs from his talk indicate the dimensions of the problem:

"The situation with respect to thermal pollution of streams is in about the same position today as was that with regard to organic pollution in about 1920. Several local areas have experienced stream damage from this source, but the problem has not been national in scope. Probably the worst condition of this type to date has been the Mahoning River at Youngstown, Ohio, where summer temperatures as high as 140° F. have been reported. In the past few years an increasing number of local cases have arisen, and * * * it can be expected that the future increase of this problem on a general scale will probably be as dramatic as that experienced with organic wastes unless the problem is recognized early, and effective measures taken to counter it.

"The peak power generation for 1954 is estimated at 85 million kw, and the predicted figure for 1970 is 249 million kw (Electrical World, *142*, No. 12; Sept. 20, 1954). This represents a doubling in 10 years. Assuming then a doubling every 15 years, by 2,000 A.D. the minimum surface runoff of 220,000 cfs for the entire United States would be heated 50° C. With further doubling every 20 years until 2,040 A.D., and every 25 years thereafter, by the year 2,081 A.D. the 220,000 cfs would be vaporized. These values assume discharge of the heat in the proper proportion to flow near the discharge point of each river system to the ocean. With heat discharged at multiple points along the river systems cooling occurs between these points * * *.

"It is not the writer's opinion that such an enormous heat discharge to surface waters will ever occur in the future. Rather, the above comparison is made to estimate the limiting case where no counter-measures are taken."

EFFECT OF HEAT UPON MICROORGANISMS

The staff of the Academy of Natural Sciences is interested in finding out just how abnormal temperature may affect the aquatic life of a river. Since a healthy river must contain the organisms that cleanse or rejuvenate it, all stages of the food chain should be considered. Although studies involving all the main classes of organisms common in rivers are now being conducted by the Academy, only two of these groups will be discussed here. Microorganisms (mostly algae) and fish have been chosen to illustrate the problems involved; the section on fish will be published in a subsequent issue.

The population of microorganisms of a river is composed of the species that are best fitted to the local ecological conditions. Because there is a fierce competition for space, a species may be eliminated by an unfavorable, rather than a lethal, factor such as increased temperature. Therefore, one must be concerned with temperatures for optimal growth more than with those that allow bare survival. There is relatively little in the literature about optimal temperatures. What is available indicates that microorganisms vary greatly as to heat tolerance.

However, certain groupings appear to be indicated. Among the algae, a large class of plants important as a source of oxygen in streams, there are three principal groups. In an unpolluted stream the diatoms generally grow best at 18° to 30° C.; the green algae at 30° to 35° C.; and the blue-green algae at 35° to 40° C., with some species growing at even higher temperatures.

This trend is illustrated by work of Wallace[1] with both pure and mixed algal cultures. These experiments were conducted under carefully controlled conditions. The medium used for culture was modified Chu 14 and controls were run in triplicate. Temperature was maintained to within $\pm$ 0.05° C. in constant-temperature baths in which thermostatically controlled knife-edge heaters worked against a coolant coil. Counts were made in a Sedgewick-Rafter counting cell at the beginning of the experiment and on the third, fifth, seventh and tenth days after inoculation.

Growth curves for individual species at various temperatures are shown in Figs. 1, 2 and 3. The brackish-water diatom *Nitzschia filiformis* (W. Sm.) Schutt grew best at 26° C. and showed no growth at 34° C. (Fig. 1). The sharp reduction in growth within the rather narrow range of 4° C. appears to be farily common in this group. In contrast, the tolerant fresh-water diatom *Gomphonema parvulum* (Kütz.) Kütz. grew best at 22° C. but still showed considerable growth at 34° C. (Fig. 2). The least tolerance to high temperatures was shown by the sensitive fresh-water diatom *Nitzschia linearis* (Ag.) W. Sm., which grew best at 22° C. and showed little or no growth at 30° C. (Fig. 3).

Low temperatures will also cause a reduction in growth. In the case of *Nitzschia linearis*, growth was inhibited at 4° C. and at 32° C. (Fig. 3). However, at 4° C. the cells remained in good condition and grew normally when the temperature was raised to 19° C. The cells exposed to 32° C. could not be revived when the temperature was reduced. This failure of all cells to survive does not appear to be typical of diatoms.

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[1] Wallace, N. M., "The Effect of Temperature on the Growth of Some Fresh-Water Diatoms." Not. Nat. Acad. Nat. Sci. Phila., No. 280, 11 pp. (1955).

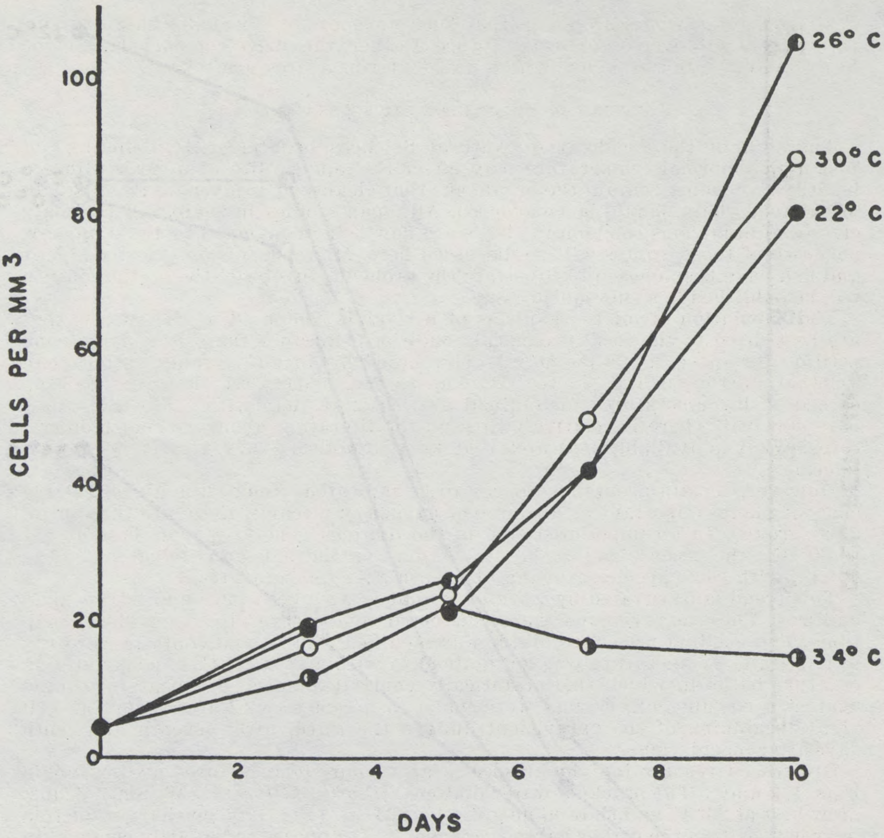

FIGURE 1. *Nitzschia Filiforms;* effect of temperature on population density (from Ref. 1).

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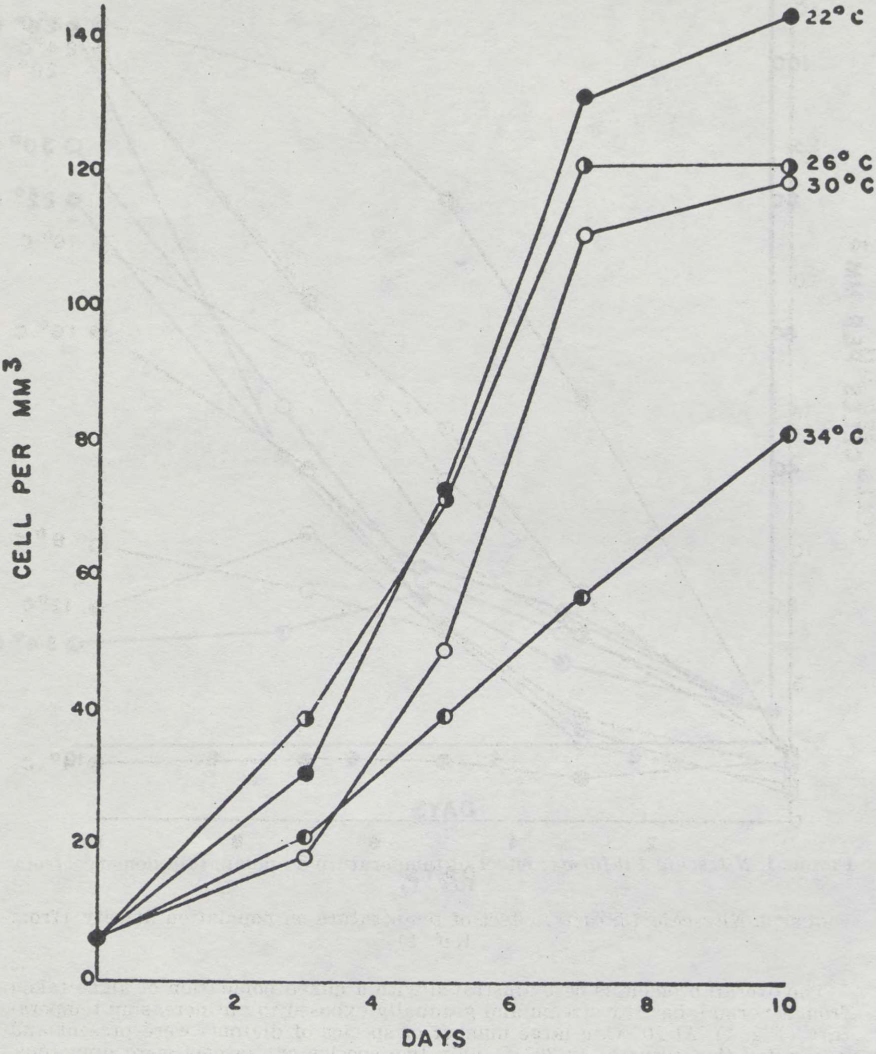

FIGURE 2. *Gomphonema Parvulum;* effect of temperature on population density (from Ref. 1).

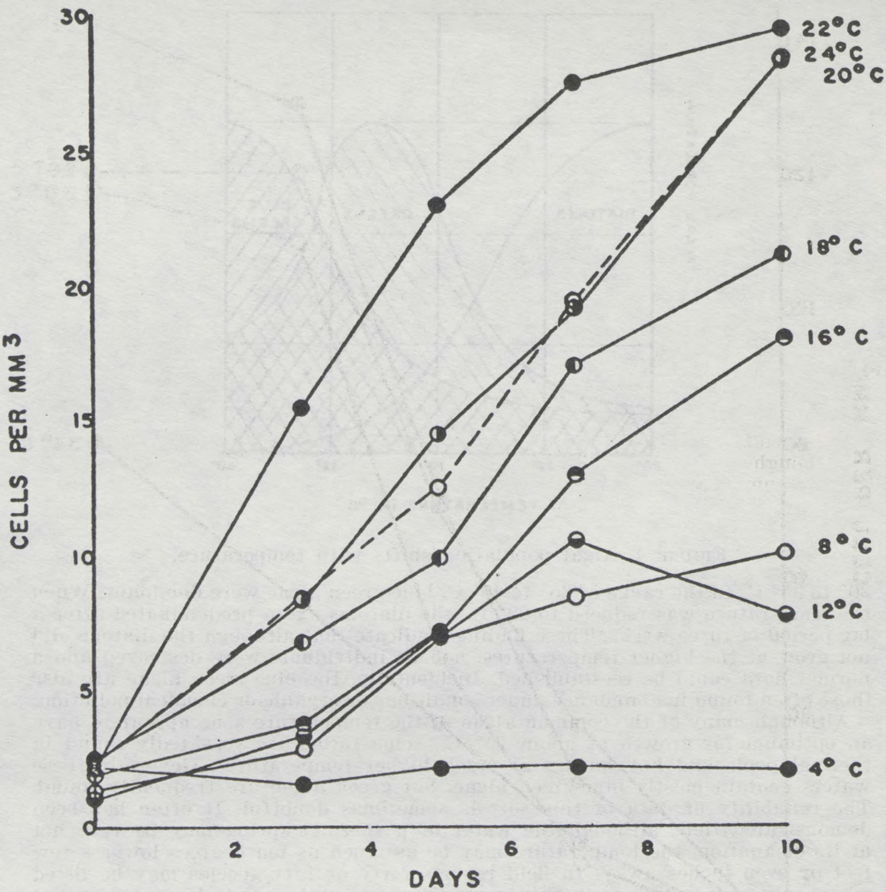

FIGURE 3. *Nitzschia Linearis;* effect of temperature on population density (from Ref. 1).

The overall problem is best illustrated with a mixed population of algae taken from a normal, healthy stream and gradually exposed to an increasing temperature (Fig. 4). At 20° C. a large number of species of diatoms were present and dominated the cultures. At 30° C. only two species of diatoms were numerous. Above 30° C. a few individual diatoms survived, but green algae predominated at

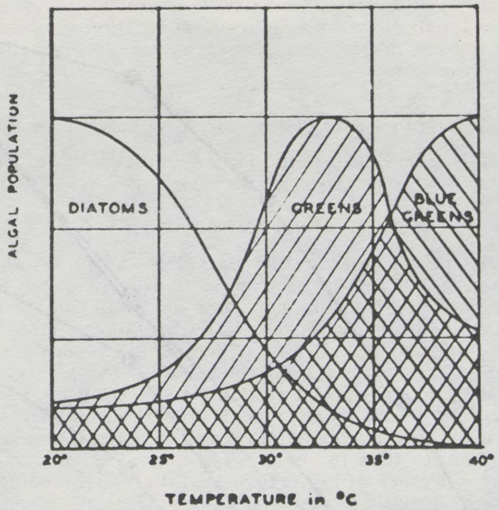

FIGURE 4. Algal population shifts with temperature.

30° to 35° C. In the range of 35° to 40° C. blue-green algae were dominant. When the temperature was reduced to 22° C., the diatoms again predominated after a lag period of three weeks. These findings indicate that although the diatoms did not grow at the higher temperatures, not all individuals were destroyed and a normal flora could be reestablished. Incidentally, the blue-green algae are also those often found in abundance under conditions or organic or chemical pollution.

Although many of the common algae of the temperature zone appear to have an optimum for growth at about 25° C., some forms are repeatedly found in thermal pools and hot springs at much higher temperatures. Generally these waters contain mostly blue-green algae, but green algae are frequently found. The reliability of data of this sort is sometimes doubtful. It often has been demonstrated that, although the water of a thermal spring may be very hot at its emanation, the temperature may be as much as ten degrees lower a few feet or even inches away. In field reports forty or fifty species may be listed when only one or two temperature readings are recorded. It is probable that the temperatures given do not always represent those at which the organisms were actually living. In addition, little is known about the rate of growth under these conditions. Furthermore, the chemical balance is usually quite different from that of a typical stream and there are strong indications that the composition of the water is an important factor in heat death of aquatic organisms. In short, field observations on organisms of thermal springs and pools can be applied only with great caution to life in normal streams.

One-celled animals, the protozoa, are also able to live only within a rather narrow temperature range, although this range is extended considerably when the animals are in an encysted or inactive state. Preliminary experiments conducted in the Academy laboratory indicate that the exact temperature tolerance varies both among different species and within a species under varied environmental conditions. This has been true for species of the genera *Paramecium*, *Halteria*, *Cyclidium*, *Chilodonella* and *Amoeba*. Chalkley[2] found that the temperature tolerance of *Paramecium caudatum* Ehr. varied with changes in pH, salinity, acidity, alkalinity and other factors.

The discussion of heat tolerance of microorganisms should not be closed without some mention of gradual acclimatization to high temperatures. Numerous experiments have shown that many species of microorganisms may become accustomed to a very high temperature if changes are small and gradual. Perhaps the classic experiment in this field is that of Dallinger[3] in which several

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[2] Chalkley, H. W., "Resistance of Paramecium to Heat as Affected by Changes in Hydrogen-Ion Concentration and in Inorganic Salt Balance in Surrounding Medium." U.S. Pub. Health Rept. 45, 481–489 (1930).

[3] Dallinger, W. H., "The President's address." Jour. Roy. Micr. Soc., Ser. 2, 7, 185–199 (1887).

flagellated protozoans were acclimated to a temperature of 70° C. over a period of seven years. The flagellates were able to survive and reproduce in the laboratory under these conditions. Unfortunately, one may expect a much lower tolerance under natural conditions.

[From Water Resources Bulletin, vol. 3, No. 4, December 1967]

THE USE OF QUALITY CONTROL TECHNIQUES IN THE MANAGEMENT OF AQUATIC ECOSYSTEMS

(By John Cairns, Jr.[1])

I believe that the new water quality standards developed this year by each state under the impetus of federal law are only a first, rather than a final step, towards a harmonious relationship with our environment. The new standards are essential and will hopefully prevent lethal conditions from developing—but will not insure the optimal[2] conditions which should be our immediate goal. In my opinion this goal will be achieved only when environmental management becomes a matter of regional concern (Cairns, 1967). Now that the first step has been taken to prevent lethal conditions, I urge that regional organizations be developed to insure the environmental quality control necessary for optimal conditions. The remarks that follow include a brief summary of the effects of pollution upon the *structure* of aquatic communities and outline the reasons for regional management. Finally a plan is suggested for carrying out such a program.

One of the increasingly important fields of study in science is *population biology.* Investigations in this field received great impetus when it became evident that biological communities are not haphazard collections of species thrown together by the whims of nature, but rather that they have a fairly well-defined structure. Changes in this structure caused by pollution should be the basis of a working relationship between biologists, engineers, and other water resource managers because (1) studies of aquatic communities will furnish information not now provided by any other system of pollution detection and (2) the data based on population structure is as easily assessed as chemical and physical data and may also be expressed quantitatively.

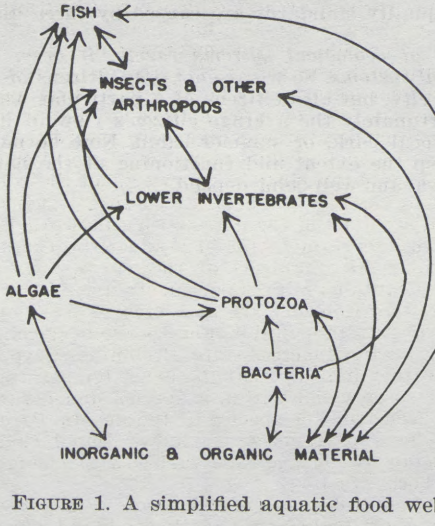

FIGURE 1. A simplified aquatic food web.

In the past pollution biologists were most interested in the *kinds* of species present. Now pollution biologists are usually most interested in *relationships* between the organisms and their environment as well as between the organisms

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[1] Department of Zoology, University of Kansas.

[2] For biologically oriented readers my own operational definition of optimal is the ability to support an aquatic community in a pattern which does not vary more than 20% from the empirically estimated maximum steady-state diversity possible in each particular locale. For non-biologists a brief discussion follows shortly.

themselves. These relationships result in communities, the structure of which seems to be determined by the energy or nutrient flow through the network of species, often called a "food web" (Fig. 1). Although the number of individuals at any one energy level may vary, the number of species playing a significant role in the web or community remains relatively constant under natural conditions. The number of components or species in this energy system also remains remarkably constant from one river basin to the next, and at various points within a basin as well (Patrick, 1961) despite the fact that the kinds of species which comprise the system may differ at various sampling points (Patrick, Cairns, Roback, 1967). Recognition of this principle obviates the need for a detailed study of a miscellaneous collection of aquatic organisms in each receiving stream and restricts the problem to the study of basic changes in the system itself. Two of the many possible ways of grouping such data are given in Figures 2, 3, and 4. *Most forms of stress (or pollution) cause a reduction in the complexity of the system or, in other words, a simplification.* From a bological point of view this is expressed by a marked reduction in species diversity (or the number of established species present). However, the number of individuals *may not change* since the species able to tolerate the stress may expand to fill the vacated niches. This might be acceptable if it were not for the fact that simplification results in increased *instability*, and complexity or high diversity in increased *stability*. (In this respect aqautic communities have something in common with industrial organizations.) The reason for this difference is that a constantly changing environment will probably only affect a small portion of the complex community at any one point in time, whereas a simplified community (consisting of a few species) might easily have half the individuals present wiped out when conditions become unfavorable for only one species. This is, of course, a very generalized summary of a very complex situation. For a more detailed discussion of the use of these concepts and techniques in solving industrial waste disposal problems see Cairns (1965, 1966). One final point on the biological assessment of pollution—it is important to recognize that biological data does not replace chemical data any more than chemical data may adequately replace biological data. They provide converging lines of evidence which supplement each other, but are not mutually exclusive. We are, hopefully, past the era of simplistic solutions to the complex problems of water management.

Difficulties in establishing a harmonious relationship between national, state, and regional water quality standards are caused by three distinct, but related factors.

1. *The boundaries of ecological systems rarely, if ever, coincide with the boundaries of political systems.* So we are not only citizens of a particular state, county, and town or city, but also citizens of a particular water shed (and air shed) as well. Unfortunately the average citizen's view of his ecosystem ends with his backyard, local park, or summer cabin. Now he must make a monumental effort to grasp the extent and functioning of the natural environment upon which his survival and well-being depend.

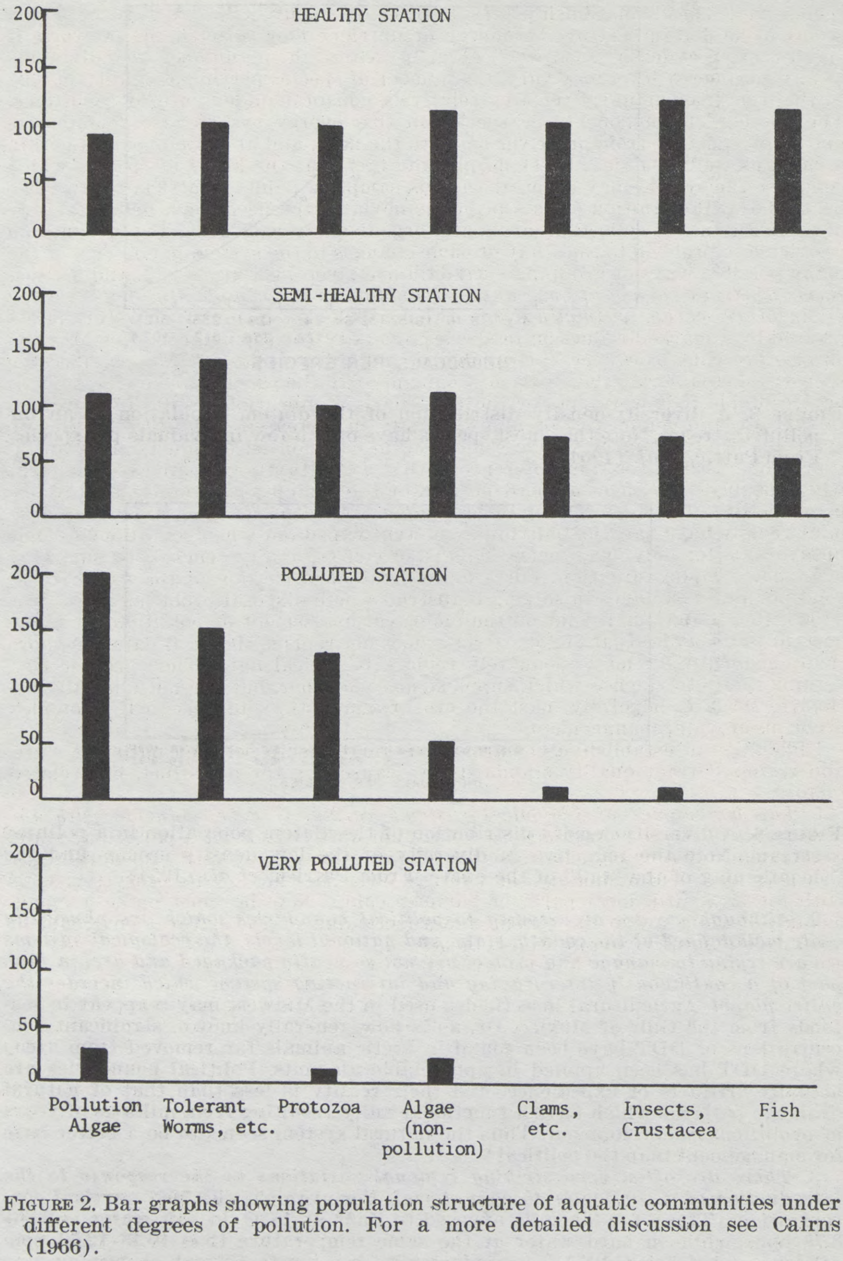

FIGURE 2. Bar graphs showing population structure of aquatic communities under different degrees of pollution. For a more detailed discussion see Cairns (1966).

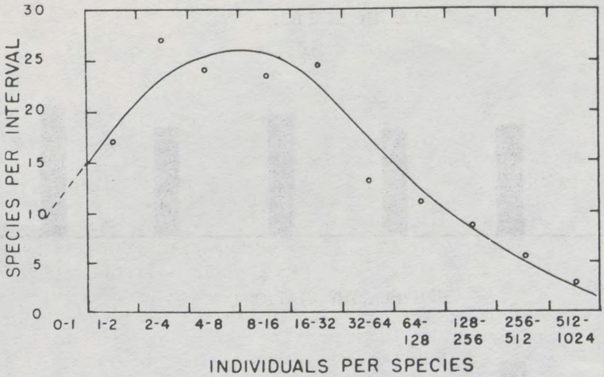

FIGURE 3. A diversity-density distribution of the diatom population in an unpolluted stream. Note that most species have only a few individuals per species. From Patric, *et al.* (1954).

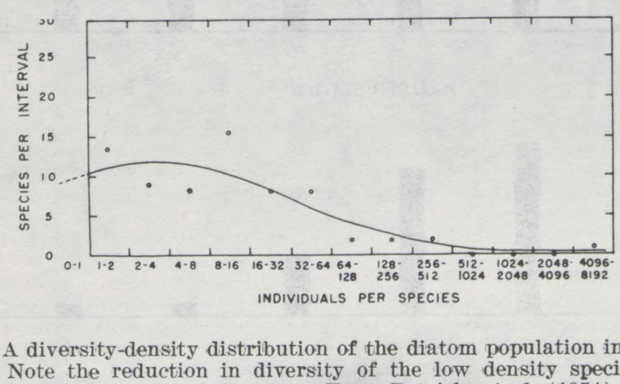

FIGURE 4. A diversity-density distribution of the diatom population in a polluted stream. Note the reduction in diversity of the low density species and the lengthening of the "tail" of the curve. From Patrick, *et al.* (1954).

2. *Although we are accustomed to political boundaries which are physically quite well defined at the county, state, and national levels, the ecological systems we are trying to manage and protect are not so neatly packaged and are, in fact, part of a continuously intergrading and interacting system which includes the entire planet.* Agricultural insecticides used in the Midwest may reappear in seafoods from the Gulf of Mexico. Or, as is now generally known, significant concentrations of DDT have been found in arctic animals far removed from areas where DDT has been applied in appreciable amounts. Political boundaries are actually artifacts of expedience, and their reality is less than that of natural drainage patterns which have a functional unity resulting from millions of years of evolutionary development. Thus the natural system seems to be a better base for management than the political!

3. *There are often very striking regional variations in the response to the introduction of a particular toxic material.* For example, the 50% survival concentration (TLm) for bluegills exposed to Zn^{**} at 18°C. in soft water is 2.86–3.78 ppm, while in hard water at the same temperature it is 10.13–12.50 ppm (Cairns and Scheier, 1957). An industry with a waste effluent containing zinc might safely dispose of larger amounts into a hard water stream than into a soft water stream. If standards are set sufficiently low to assure safety for both streams, the plant located on the hard water system is prohibited from making full use of its carrying capacity. On the other hand, a law based on the average response of the two systems would result in fish kills and other problems in the soft water stream. Thus it is quite clear that water quality control to insure *optimal* conditions must be a matter of regional concern. There are numerous examples of this type for a variety of environmental factors.

What then should be the relationship between national, state, and regional water quality criteria? If we consider our water management objectives this becomes quite clear. These are: (1) *To prevent gross abuse of the environment from lack of local stewardship.* (2) *To develop healthy, well-balanced ecosystems*[3] *which function vigorously and as a result have a wide variety of beneficial uses.* The present condition of "fresh" waters in many areas of the United States shows quite clearly that we should not depend entirely on local stewardship either at state or regional levels to prevent serious damage to our streams and lakes. Thus it is quite evident that we need broad, general national laws to avoid fish kills and to prevent other lethal or catastrophic conditions from developing.

However, establishing criteria that merely prevent catastrophe will not insure a *properly functioning* aquatic community which is essential to the ecosystem of which it is a part. And since the ability of such an aquatic community to resist and transform various wastes depends upon its condition, it is not enough that the community referred to barely survives; rather it must be healthy and function vigorously. We must therefore apply the concept of "quality control" to the most fundamental of nature's productions, viz., to the ecosystems which support life. In order to do this we cannot merely set arbitrary standards for all systems, but rather we should establish the optimal conditions needed for *each* system and *each* region. Obviously this will require continuous regional surveillance of all the conditions which seriously affect the functioning of the aquatic communities concerned if the most beneficial use of each drainage basin is to become possible.

Our adjustment to our environment may thus be viewed as a two-stage process. The coarse adjustment would establish a non-lethal though not necessarily beneficial relationship. Water quality criteria developed toward this end would permit survival of the aquatic community and its ecosystem but would not necessarily produce optimal functioning. Developing such criteria (which ensures that local or regional conditions meet *minimal* standards) should be a matter of national concern since historically gross abuse of the environment is quite frequent in the absence of national standards. The fine adjustment to the environment would be concerned with optimal functioning of each ecosystem, and would be a matter of regional concern. This would require continuous surveillance of all important water quality criteria as well as a vast educational program to convince people that a harmonious relationship with their environment is in their own enlightened self-interest.

Since I still hear and read proposals that it is both economically sound and desirable to use our rivers as sewers, I will deal briefly with this point. Though we talk of a consumer society, we really *use* and discard food, water, and industrial wastes which must then be transformed before they are again acceptable for further use. Failure to do so means living in a vast cesspool. We must either carry out this transformation entirely by ourselves, at great expense, or use our natural ecosystems to their fullest capacity without degrading them and carry out partial treatment before discharging wastes. It hardly seems necessary to mention that the sooner wastes are transformed into acceptable materials the better.

Results will probably be achieved most rapidly within the organizational framework of a drainage basin association with far more authority and control over water quality than those now in existence. In short, I suggest that the methods for proper management of a river basin are quite similar to those already practiced by industries using its water (i.e., data collection and feedback, control of quantity and quality of material entering the system, a set of standards for the final product, and coordination of the components of the system so as to achieve and maintain quality control on the product). This drainage basin association concept, while certainly not new, has not yet resulted in the evolution of water quality surveillance, information feedback, and immediate control of effluent quality and quantity on a scale sufficient to manage waste loadings with the precision necessary to permit optimal functioning of the aquatic ecosystem at all times. The components of the system needed for such successful management are already being developed. First, we are attempting to regulate quantity of water to insure minimal flows in many areas. In some basins with multiple reservoirs and water of different characteristics, flow regulation may also control quality. Second, continually operating chemical and physical monitoring systems are being installed in many basins (though it should be emphasized that these measure only a few of the many qualities of water) and biological assessment

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[3] The operational definition for these is essentially that given on the first page for the result of optimal conditions.

is increasing although pitifully short of existing needs. Finally, most industries and municipalities have some record of the quantity and quality of the waste being discharged. These efforts need only to be *coordinated* and expaned to provie the system needed. If an organization *with sufficient authority* is developed, good management of the ecosystem may become a reality. Flexible legislation permitting regional management to obtain optimal conditions is as badly needed as are national minimal quality standards to prevent gross damage to the environment. Within this framework our ecosystems may be managed to serve a greater variety of beneficial uses. In addition, the waste transforming capacity of a well-managed system would actually be far greater than that of a poorly managed, barely surviving one, and therefore of greater economic value to the industries using it.

Although we regularly hear proposals (some ironically by people "representing" water pollution control agencies) that the most beneficial, economical, and practical use of our rivers is to carry wastes to the sea, one hopes that the people making these statements will eventually realize that a sick environment cannot support a healthy human race. Society may also eventually recognize that *slum ecosystems* have a way of spreading, and in many ways have comparable detrimental effects upon the ecological environment as do the city slums upon the urban environment. Environmental management on the scale I have proposed will be repugnant to many resource managers, but I suggest that it will provide a better aquatic ecosystem than those now found in most densely populated industrial regions of the world.

ACKNOWLEDGMENTS

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REPORT PREPARED BY THE OHIO RIVER VALLEY WATER SANITATION COMMISSION

[From the Environmental Science and Technology, November 1967]

Aquatic Life Water Quality Criteria

ORSANCO—HOW IT BEGAN

On June 30, 1948, the states of Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia, and West Virginia signed a compact. It was an agreement written by them, supported by their respective legislatures, and approved by the Congress of the United States. Under the terms of the compact the eight states pledged a pooling of their resources and their police powers for the control of interstate water pollution.

To carry out this purpose the states created the Ohio River Valley Water Sanitation Commission (ORSANCO). The membership includes three representatives from each state appointed by the governor of the state, and three from the Federal Government appointed by the President of the United States. The role of the commissioners is to execute the compact provisions and to assert such powers as may be necessary for the enforcement of obligations. For administration of commission functions the states maintain a staff and headquarters at Cincinnati, the cost of which is assessed on a proportionate basis among them.

Signing of the compact gave substance to a dream. That dream envisioned the potentialities of joint action among the states in the Ohio Valley in tackling a job that none could do alone. Guided by the broad principle that no sewage or industrial-waste discharge originating within a signatory state shall injuriously affect the uses of interstate waters, the commission is empowered to make determinations regarding control measures. Securing compliance with these measures then becomes an obligation of each state. To supplement state efforts the commission is clothed with residual enforcement powers.

An assessment of findings from recent research makes it desirable for the Aquatic Life Advisory Committee (ALAC) to reconsider the various criteria for water quality discussed in its first three progress reports to the Ohio River Valley Water Sanitation Commission (ORSANCO). Since data are not available for many contaminants and since bioassay must continue to be the major basis for evaluating water quality, only criteria of wide application have been considered in this progress report.

Efforts now in progress to develop water quality standards for interstate waters have highlighted the difficulty of many regulatory bodies and advisory groups to make a distinction between *criteria* and *standards* as related to water quality. Therefore, ALAC has adopted the following definitions for use in its deliberations and reports:

- *Criteria:* Water quality requirements of aquatic life which will permit a sustained yield of desired game and commercial fish and maintenance of a well-rounded fish population.
- *Standards:* Water quality levels which are promulgated by administrative or legislative bodies in accordance with technologic, economic, and sociologic factors associated with the use requirements of particular waters and which are legally enforceable.

It is important to recognize that *criteria are relatively inflexible* since they are based on professional conclusions relating to the biological needs of the organisms. On the other hand, *standards reflect judgments* of the relative importance of desired uses in each body of water or section of stream. The function of ALAC is the establishment of aquatic life water quality criteria. It is not the prerogative of ALAC to recommend standards for any stream in the Ohio River Basin.

In situations where sustained fish production from a well-rounded species complex is the primary objective of stream standards, the established criteria and standards should be the same. Where other uses are more important, the choice of standards may show departures from the criteria. However, it should be clearly understood that any significant divergence from the recommended criteria will result in a lower sustained fish production than can be expected from a well-rounded species complex.

DISSOLVED OXYGEN

Many studies of the influence of dissolved oxygen on fresh-water fishes have been reported since the appraisal and recommendations of ALAC were first issued in 1955. However, because these studies have provided few new insights into the problems of delineating dissolved oxygen criteria for the protection of aquatic life, the criteria previously recommended and widely accepted are still valid. These values are intermediate between the highest and lowest levels that can reasonably be accepted for practicable applications.

In the first progress report of ALAC (1955)', dissolved oxygen requirements were enunciated for the maintenance of fresh-water fish populations in the Ohio Valley. The recommendations in the report are:

> The dissolved oxygen content of warm-water fish habitats shall be not less than 5 p.p.m. during at least 16 hours of any 24-hour period. It may be less than 5 p.p.m. for a period not to exceed 8 hours within any 24-hour period, but at no time shall the oxygen content be less than 3 p.p.m. To sustain a coarse fish population the dissolved oxygen concentration may be less than 5 p.p.m. for a period of not more than 8 hours out of any 24-hour period, but at no time shall the concentration be below 2 p.p.m.

Based on this recommendation, ORSANCO adopted the following dissolved oxygen requirements for aquatic life in the ORSANCO Stream-Quality Criteria and Minimum Conditions (RESOLUTION No. 16–66, Adopted May 12, 1966, Amended September 8, 1966):

> *Dissolved oxygen.* Not less than 5.0 mg./1. during at least 16 hours of any 24-hour period, nor less than 3.0 mg./1. at any time.

Determing compliance with this specification poses practical difficulties in some cases because it requires measurement of 24 hourly values during each 24-hour period. Although equipment is available for such monitoring, with the exception of the ORSANCO robot-monitor network, such facilities are not in general use. There is a need, therefore, for a substitute or surrogate measure to determine compliance with the criteria.

Statistical evaluation of long term dissolved oxygen data for the Ohio River by the staff of ORSANCO has revealed the following: When the daily average concentration is 4 mg./1. or more, the minimum value will exceed 3 mg./1., but the maximum value usually will not exceed 5 mg./1. Such levels of dissolved oxygen appear adequate to support a well-rounded warm-water fish population in the Ohio Valley, but do not precisely meet the criteria adopted by ORSANCO.

More recently the commission has requested recommendations on dissolved oxygen requirements for the maintance of cold-water fish habitats. In the Ohio Valley this type of stream falls into two categories: streams dependent on natural propagation to maintain trout; and streams in which hatchery-reared trout are stocked on a put-and-take basis.

RECOMMENDATIONS—DISSOLVED OXYGEN

On the basis of the foregoing considerations, ALAC recommends that the dissolved oxygen requirements for fresh-water fish outlined in its first progress report be interpreted in the following manner.

1. Habitats for well-rounded warm-water fish populations: DO concentration shall not be less than 4.0 mg./1. at any time or any place.
2. Habitats for commercial, nongame, and forage fish species: DO concentration shall not be less than 3.0 mg./1. at any time or any place.
3. Habitats for cold-water fish: DO concentration shall not be less than 5.0 mg./1. at any time or at any place.
4. Oxygen demand of the stream shall be maintained at a level which permits normal diurnal and seasonal variation above the minimum levels specified.

TEMPERATURE

A re-evaluation of the earlier literature on temperature requirements of fish and consideration of recent literature (Wurtz and Renn, 1965; Patrick, 1966; and Mihursky and Kennedy, 1966) have shown that current research either confirms earlier findings or makes slight refinements on knowledge of temperature relationship of a wider range of animals.

Temperature is a major factor affecting suitability of an aquatic environment for fish and fish-food organisms. It has long been known that aquatic organisms are very sensitive to temperature and that each species has a specific temperature range.

The effect of physical and chemical properties of water on fish and other organisms is greatly influenced by temperature. As cold water warms, it holds less dissolved oxygen. As a consequence of warming, most aquatic organisms become more active and use more dissolved oxygen. This oxygen change and increased utilization brings about changes in carbon dioxide and other elements in solution or suspension. Hence, temperature affects the suitability of the environment in more ways than its direct physiological effect on the biota.

During the past two decades much research has been devoted to determination of the lethal temperature limits for fish, and a long list of mean heat tolerance limits of fish has been compiled. These studies have shown that the temperature to which a fish has become acclimatized determines its heat tolerance limits. Hence, the range of the tolerance limits may be altered by different acclimatization conditions.

The results, while showing fish adaptability, cannot be applied directly to fish-producing waters because they do not take temperature preferences of different species into account. Some studies have shown that temperatures at which fish will survive for relatively long periods may ultimately kill them, prevent growth or reproduction, or make them susceptible to other stressing factors to such an extent that sustained fish production is eliminated. Usually the acclimatization process is gradual. Therefore, sudden and abrupt changes may cause mortality within the apparent tolerance range.

In developing the temperature recommendations of the second progress report (ALAC, 1956), the committee was concerned with streams of the Ohio River watershed rather than establishment of a nationwide formula. The recommendations in that report were made to insure that stream conditions would be maintained which would permit production of an annual harvestable fish crop comparable to that in natural waters of the area. The temperature limits specified for Ohio Valley streams were that water:

1. Should not be raised above 34° C. (93° F.) at any place or at any time;
2. Should not be raised above 23° C. (73° F.) at any place or at any time during the months of December through April; and
3. Should not be raised in streams suitable for trout propagation.

Industry advisory committees of ORSANCO in requesting a review and revaluation of the ALAC recommendations, in effect have said the following:

Present criteria are severe and restrictive and may force the use of cooling towers.

Present criteria do not recognize admixture or thermal dissipation zones.

There does not appear to be any basis for revising the 93° F. temperature limitation.

The 73° F. temperature limitation during December through April should be removed, but spawning areas should be protected through control of admixture and thermal dissipation zones.

Thermal barriers should be avoided.

In consideration of maximum temperature levels for warm-water streams, there is no available evidence which indicates that higher temperatures than those specified in the original recommendations can be tolerated without reduction in the suitability of aquatic environments for normal fish production capacity. There are indications that the 93° F. level now specified may be too high. Mihursky and Kennedy (1966), point out that frequent or prolonged occurrence of this temperature in streams will cause a reduction in the number of species. They state further that optimum feeding and growth of any warm-water game species requires that water temperature not exceed 85° F. even for brief periods.

The 73° F. limitation specified for the months of December through April is related to spawning requirements of fish and the development of fish-food organisms. Winter temperatures must remain low in order that gradual warming will stimulate and permit normal spawning of game fishes. The growth and reproduction of fish-food organisms which occur during this warning period are also important because successful survival of newly hatched and juvenile fish depends on availability of proper food at various stages of growth. The winter temperature originally recommended was too high to insure the proper sequencing of spawning and food development.

Organisms that rely on temperature variation to initiate physiological changes which lead to reproduction may be induced by artificially heated water to spawn while unfavorable conditions for newly hatched fish generally prevail.

Species vary in their ability to tolerate heat as shown by Bailey (1955), who found that in a mixed population of warm-water fish in a Michigan pond where temperature rose to approximately 100° F. the mortality was higher among the catostomids, cyprinids, ictalurids, and percids than among cyprinodontids, pociliids, and centrarchids.

Still another effect of high temperature is to increase the toxicity of certain substances. The toxicity of cyanide has been shown by Alexander, Southgate, and Bassindale (1935) to increase rapidly with a rise in temperature, and by Downing (1954) to increase also with a decline in the dissolved oxygen content of the water.

Markowski (1959) found no difference in the composition, either qualitatively or quantitatively, of the invertebrate fauna of the influent and effluent water from three power stations in England which were studied in some detail. The fresh water used by two stations had 35 species and the brackish water of the third had 62 species. The temperature of the discharge, which averaged 72° to 88° F., was usually 14° F. greater than that of the intake and sometimes considerably higher. Markowski (1959) found no detrimental effect upon the organisms from their passage through the condensers.

Where heated water is discharged to a stream, a zone of admixture usually will be distinguished, but the conditions within this zone and its extent must be carefully controlled to prevent undue damage to the stream. (These conditions are discussed in a subsequent section.)

Trout fisheries are limited in size, extent, and general distribution in the Ohio River Basin. Consequently, they are of high economic value and occupy a favored position as a recreation asset. Trout require lower temperatures than warm-water fish. Mihursky and Kennedy (1966) concluded there was ample justification for the Pennsylvania standard of a 58° F. maximum temperature during the winter and a summer maximum not to exceed natural conditions to insure best fish production. The recommendation for Pennsylvania trout streams is acceptable under certain conditions. It provides "that no wastes or waters shall be added from any source having temperatures in excess of those of the receiving waters except that during the period October through May, when stream temperatures are below 58° F., the temperature of wastes discharged to the stream shall not exceed 58° F."

RECOMMENDATIONS-TEMPERATURE

On the basis of the foregoing considerations and in the light of available data on temperature requirements for fish production in streams the committee recommends:

1. To maintain well-rounded warm-water and commercial nongame and forage fish habitats:
   a. Stream temperatures shall not exceed 93° F. at any time or any place, and a daily mean of 90° F. should not be exceeded.
   b. The temperature shall be below 55° F. during December, January, and February.
   c. The months of March, April, October, and November shall be transition periods during which the temperature can be changed gradually by not more than 7° F. per day.
2. To maintain trout habitats: Stream temperature shall not exceed 55° F. during the months of October through May, nor exceed 68° F. during the months of June through September, and insofar as possible, the temperature should not be raised in streams used for natural propogation of trout.

TOXICITY

Although bioassays have been in active use for more than 25 years, only recently has there been an increased recognition of their importance and use in evaluating toxicity problems related to the maintenance of aquatic life in streams. As the use of bioassays has become more widespread and the number of workers in the field has increased, a variety of procedures and methods of reporting results has been developed. This wider use has also lead to some confusion and lack of coordination, and the need for some uniformity in test methods, test organisms, and the reporting of the results. In many instances it has been almost impossible to compare the results of different investigators.

The first attempt to establish more uniform procedures was made by a committee of the Federation of Sewage and Industrial Wastes Association (now the Water Pollution Control Federation) in 1949 and 1950. Recommendations of this committee were published in 1951 in the *Sewage and Industrial Wastes Journal* (now *Journal, Water Pollution Control Federation*). A few years later a toxicity subcommittee was established in the Standard Methods Committee of the Federation to prepare recommended bioassay procedures for the eleventh edition of "Standard Methods for the Examination of Water and Waste Waters" (Standard Methods, 1960). With publication of the methods, bioassays were recognized as having authoritative and legal standing.

Procedures and equipment vary with the objective and purpose of the bioassay. The tests, for example, may be used to determine the relative toxicity of various materials to the same organism or group of organisms or they may be carried out to determine the most sensitive species in the aquatic biota to a particular toxicant or potential toxicant. Most bioassays have been used to determine the acute toxicity of specific materials or wastes to selected organisms. In these studies the dilution water is either natural water with specific qualities or a prepared water having predetermined hardness and pH or water from a receiving stream. Local species are usually employed as test organisms in order to relate studies directly to the local problem.

In preparing for a series of short-term static bioassays to determine acute toxicity, it is desirable to make exploratory studies to gain some idea of the range in concentration of waste to be tested in the five replications normally used in bioassay investigations. It is desirable to set up the five concentrations so that the one lethal to 50% of the test organisms within each prescribed test period can be found or estimated by interpolation. The exploratory bioassays of 24-hour duration are usually made with two to five fish in each container.

The amount of the waste or toxicant added to a test chamber may bear little relation to the actual concentration to which the fish are exposed. The concentration may be reduced through violatilization, collection on the walls of the jars, or precipitation. Further reduction may occur through adsorption by the silt and organic materials in the test water, or the test organisms themselves may remove a portion. It is recommended, therefore, that analysis be made to determine the concentration of the toxicant to which the test organisms are actually exposed.

In studies to determine the safe levels of potential toxicants under conditions of continuous exposure, it is necessary to use a flow-through type of bioassay where the dilution water and the toxicant are continually renewed. With continual renewal of the toxicant actual exposures will more nearly approach the amounts being added. However, there may be some decrease in concentrations in continually renewed solutions. Therefore, daily analysis of the waste concentration during the entire period of exposure is desirable. Flow-through type studies are also desirable because metabolites are continuously removed, more test organisms can be accommodated, and tests more nearly resemble stream conditions where waste material is continuously added.

With certain exceptions, it is recommended that the comparative toxicity and sensitivity tests be carried out in accordance with the recommendation in the twelfth edition of "Standard Methods for the Examination of Water and Waste Waters," Part VI, entitled "Bioassay Methods for the Evaluation of Acute Toxicity of Industrial Wastes and Other Substances to Fishes" (Standard Methods, 1965).

In studies to determine the most sensitive species or life history stage to a particular waste or toxicant, it is essential that all important organisms in the aquatic biota be considered. In these studies the prime requisite is comparability which requires standard methods and standard water. A standard water for fishes can be quite simple. However, since the entire biota including invertebrates and plankton organisms must be considered, the development of a standard water becomes more complex. It is apparent that the prime consideration in the development of such a water is to insure that it is suitable for the various plankton organisms, especially the phytoplankton, to avoid losses in the controls during the test. Naturally occurring salts and nutrients should be present in sufficient quantities to maintain the organisms during the period of the test, but not necessarily adequate for rearing. With the phytoplankton this period may be only a few days.

For the long-term studies to determine safe levels of potential toxicants under conditions of continuous exposure, it will probably be necessary to carry them through one or two generations of the test organism. In the future, when more data becomes available, shortcut methods may be developed that will give long term effects through short term studies. The most promising fields for the development of such short term methods lie in physiological, histological, toxicological, pathological, enzymatic, and metabolic studies.

Since long term studies are now under development, is is premature to suggest standard methods. Within the near future there will be methods which have been widely tested and these can be suggested for consideration.

Recommendations contained in "Standard Methods" for the keeping and preparation of test organisms are suitable for the sensitivity tests. In long term flow-through tests, it will be essential to feed test organisms. They should be acclimated and taught to feed on the diet supplied before the long term tests are initiated.

In long-term studies, samples of the test organisms should be taken periodically to determine their condition and their growth. Physiological, histological, enzymatic, hormonal, and metabolic studies should be carried on in conjunction with bioassay tests where possible to determine sub-lethal effects and the concentrations at which there are no harmful effects.

RECOMMENDATIONS—TOXICITY

For the purpose of determining acceptable levels of toxic wastes in Ohio Basin streams, ALAC recommends bioassay tests with the following criteria:

1. The final concentration of any waste in the receiving water should not exceed one tenth of the 96-hour median tolerance limit (TL_m), except that other limiting concentrations (for example, application factor) may be used in specific cases when justified on the basis of available evidence and approved by the appropriate regulatory agency.

2. For water containing wastes composed chiefly of stable components of moderate toxicity without measurable oxygen demand, the static bioassay may be used to determine TL_m value. For water containing unstable or volatile components with a measurable oxygen demand, the flow-through bioassay shall be used.

HYDROGEN-ION CONCENTRATION

The pH of most streams in the continental U.S. varies between 6.4 and 8.5, although various exceptions have been reported, particularly in streams affected by coal mine wastes. Acid lakes in Florida may be lower, pH 5.2, while some acid mine streams may be as low as pH 1.2. On the other hand some western streams may be higher than pH 9.0.

These data have little reference to stream biota. For example, speckled trout occurring naturally in waters with a pH varying from 4.1 to 8.5 showed no apparent harm when subjected to waters having a pH of 3.3 to 10.7. Varied wide tolerance ranges could be cited for other species also, but the concern is with all the stream animals and plants among the many food-chain organisms and aquatic plants which make up the ecosystem of the stream.

Naturally occurring values of pH in the Ohio Basin may vary between 6.4 and 8.5, but many productive natural waters are either below pH 6.4 or above 8.5 Therefore, a range of pH 6.0 to 8.5 would appear to be suitable for aquatic life in the basin. How long these values may be exceeded without damage to the biota requires careful examination. It is almost certain that levels as high as pH 9.0 may occur in the stilled surface waters behind dams when summer phytoplankton blooms occur. Abundant and varied biotas for many situations whose pH is below 6.0 and above 8.5 have been demonstrated in areas outside the Ohio Basin and may occur within it, so that pH values between 6.0 and 8.5 are not extreme.

The minimum and maximum values of pH 5.0 and 9.0 as given for aquatic life in the ORSANCO Stream-Quality Criteria (RESOLUTION No. 16–66), rarely occur in the Ohio Basin except for the low values found in acid impregnated streams. Unless definite information to the contrary becomes available, these values must be considered restrictive to aquatic life, especially when maintained for periods longer than 24 hours.

RECOMMENDATIONS-HYDROGEN-ION CONCENTRATION

The committee recommends that in commercial, nongame, forage, and warm-water fish habitats in the Ohio Basin streams:

1. pH values should be maintained between 6.0 and 8.5.
2. Daily fluctuations which exceed pH 8.5 and are correlated with photosynthetic activity, may be tolerated. However, any sudden drop below pH 6.0 or sudden rise above 8.5, not related to photosynthesis, indicates abnormal conditions which should be investigated immediately.

MIXING ZONES

There is little published information on how pollutants may be introduced into streams to minimize adverse biological effects. General recommendations concerning mixing zones may be drawn inferentially from the considerable body of knowledge now at hand on the biological effects of most types of pollutants. Hydrological factors must be taken into account in applying a regulation, but they need not become a part of the regulation.

The primary aim of any requirement pertaining to mixing zones is to protect the biota of the stream to an extent that it will support a fishery. This aim will be fulfilled only if the stream retains conditions suitable for normal growth and reproduction of a varied fauna and flora, including a variety of invertebrates, and provides for the normal migration of fishes and invertebrates.

A stream either does or does not meet the minimum requirements for supporting a harvestable crop of warm-water fishes. Barriers to movement of fish and other organisms, whether physical, thermal, or chemical (these types of factors are not separable in their effects), are detrimental to the welfare of many species and are not compatible with the fullest use of the stream for production of fish and other aquatic organisms. ALAC is of the opinion that zones in which the existing recommended criteria are exceeded will act as barriers and will proportionally reduce the production of aquatic life in the stream as a whole.

The committee concludes, therefore, that it would be inadvisable to establish a separate set of criteria for mixing and dissipation zones.

Any permanent blockage of a stream, such as a waterfall, is normally followed by a reduction of fauna. But a mixing zone which extends entirely across a stream may have deleterious effects other than those of simple blockage. Conditions that interfere with normal activity, for example, although not directly lethal may ultimately result in ecological disadvantage or mortality. In addition, natural conditions are often more demanding than those of the experimental tank. Therefore, the incipient lethal level as determined in the laboratory may be grossly inadequate as a criterion for stream application.

Rapid change of temperature may also be dangerous. Fish acclimated to a warm zone in winter may be endangered if they move into colder water, if the input of heated water is interrupted, or if the volume of streamflow increases greatly. For these reasons it is desirable to maintain a relatively uniform temperature immediately below a mixing zone or within that portion of the zone which is attractive to fish. It is also essential that such areas do not undergo rapid changes in temperature.

Trembley (1956–59) has reported that the fish population of the Delaware River has not suffered notable effects from the heated condenser discharge from the Martins Creek steam electric station. Although practically all species disappear from the heated zone during the warmer months (when the temperature approaches or exceeds 90° F.) there is in the cooler months a strong tendency for various species to congregate in the heated zone and thereby to prolong their period of feeding. Four anadromous species were found to migrate through the area. It is probably significant that the heated zone did not extend all the way across the river and that a fairly broad passage of unaffected water remained.

The capacity of fish to avoid toxic substances varies with different species of fish and with different substances. Jones (1947) found that sticklebacks are apparently unable to detect copper sulfate over the relatively wide range of $0.1N$ to $0.001N$. His experimental fish swam unhesitatingly into and out of the solution until, finally, in a stupor, they remained in the solution to perish. It is essential, therefore, that fish and other organisms have the opportunity to by-pass mixing zones without having to enter regions with lethal or sublethal effects.

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RECOMMENDATIONS-MIXING ZONES

On the basis of the considerations discussed above the committee recommends that:

1. No separate criteria be established for those sections of streams into which pollutants are being discharged.
2. Zones of admixture shall not extend entirely across a stream, but shall leave at all times and throughout the entire length of the zone a passageway adequate for migration, but consisting of not less than one fourth of the width and one fourth of the cross section of the stream.
3. Toxic wastes shall be mixed thoroughly and rapidly with the receiving water in the mixing zone.

RADIOACTIVITY

Radioactivity as related to conditions for aquatic life is documented in ALAC's third progress report (1960). The rapid expansion and use of nuclear energy by government agencies and private companies has placed added emphasis on the need for instituting safeguards for the protection of aquatic life. In this connection it should be noted that aquatic organisms are subjected to continuous exposure to radiation from waste discharges, as contrasted to occasional or periodic exposure of terrestrial forms.

Although existing types of radionuclides are known, new advances in technology may require additional information on the following:

The types of concentrations of radionuclides in effluents and receiving streams adjacent to nuclear plants.

Possible influence of temperature on biological survival where radionuclides are present.

The rate and uniformity of admixture of effluents with the receiving water.

The distance between nuclear plants needed to minimize downstream radioactivity.

With respect to accumulated radionuclides in aquatic species, it may be stated that adult systems are in no immediate danger. Little information is available concerning the sensitivity of different developmental stages of aquatic species, but in general, younger animals are known to be very radiosensitive at certain times in their life cycle (Polikarpov, 1966).

Polikarpov (1966) found that some aquatic species undergo physiological changes when radioactivity levels in water approach or exceed 100 pCi./1. It might also be noted that the National Committee on Radiation Protection has recommended 100 pCi./1. as a maximum permissible concentration for continuous exposure (of human beings) to unidentified radionuclides (Handbook 69, 1959).

In view of these findings, and until more is known about the radiosensitivity of aquatic species, ALAC is of the opinion that adequate protection to all forms of aquatic life will be provided if radioactivity levels in waste discharges are not allowed to exceed 100 pCi./1.

In suggesting the use of effluent criteria, ALAC is aware that the establishment of such criteria is a departure from the normal practice of setting stream criteria. However, because of the unique problems associated with the quantitative analysis of radioactive substances in streams, ALAC believes that the use of effluent criteria, which provide more positive control and are more easily applied, is justified.

ALAC further recommends that a suitable stream monitoring program should be carried out in the vicinity of radioactive discharges. Such a program should include the periodic measurement of radioactivity in the river water, silt, and biota upstream and downstream from the point of discharge.

Since 1952 an eminent group of biologists and fisheries scientists has been serving as an Aquatic Life Advisory Committee (ALAC) to the Ohio River Valley Water Sanitation Commission (ORSANCO). Their task has been to assist ORSANCO in the formulation of criteria for water quality with reference to the protection of fish and other aquatic life.

This report is the fourth to be made by the committee. The first (1955) dealt with dissolved oxygen requirements, hydrogen-ion concentration, and criteria for judging toxicity of wastes by bioassay. The second report (1956) set forth findings with regard to temperature, dissolved solids, settleable solids, chloride ion, fluoride ion, and color; also included were supplementary data on the validity of dissolved oxygen requirements. The third report (1960) discussed radioactivity and aquatic life, detergents, cyanides, phenolic compounds, iron, and manganese.

In the current report, the committee has updated earlier recommendations regarding criteria for dissolved oxygen, temperature, pH, toxicity, and radioactivity. The committee has re-evaluated previous findings and has made an assessment of findings and conclusions from recent research. Some of the earlier recommendations on criteria have been re-interpreted to provide more workable guidelines for judging the suitability of stream conditions for aquatic life. For the first time in this series of reports, the committee has developed recommendations regarding the protection of aquatic life in mixing zones immediately below points of waste discharge.

RECOMMENDATION-RADIOACTIVITY

On the basis of the foregoing considerations the committee recommends: The concentration of radionuclides in an effluent shall have a gross activity (alpha, beta, and gamma radiation) not exceeding 100 pCi./1.

The committee includes the following members:

Lloyd L. Smith, Jr., Department of Entomology, Fisheries, and Wildlife, University of Minnesota, Chairman.

Bertil G. Anderson, Department of Zoology, Pennsylvania State University.

William M. Clay, Biology Department, University of Louisville.

Howard Dean, New York State Fish Hatchery and Laboratory.

Raymond E. Johnson, Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service.

Adolph T. Krebs, Division of Nuclear Medicine, Walter Reed Army Institute of Research.

James B. Lackey, Department of Civil Engineering, University of Florida (retired).

Theodore Olson, School of Public Health, University of Minnesota.

Edward Schneberger, Wisconsin Conservation Commission.

William A. Spoor, Department of Biological Sciences, University of Cincinnati.

Clarence M. Tarzwell, National Marine Water Quality Laboratory, Federal Water Pollution Control Administration.

Serving as secretary to the committee is William L. Klein, chemist-biologist on the commission staff.

In making this report (submitted to ORSANCO, Sept. 14, 1967) available for publication the commission wishes to acknowledge its appreciation of the valued contributions made by its Aquatic Life Advisory Committee.

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HEATED EFFLUENTS AND EFFECTS ON AQUATIC LIFE

WITH EMPHASIS ON FISHES

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This bibliography was prepared at the suggestion and with the help of Stanley Moyer of the Philadelphia Electric Company. The first edition, which appeared under the title of "Heated Discharges and Effects on Aquatic Life with Emphasis on Fishes" was mimeographed on 19 October 1966. It included more than 475 references. The edition of 300 copies was soon exhausted and after receiving more than 250 additional requests this edition was undertaken.

After the first 66 pages, which included 879 entries, were typed we received a copy of a "Bibliography on the Effects of Temperature in the Aquatic Environment" by V. S. Kennedy and J. A. Mihursky, University of Maryland, Natural Resources Institute, Contribution No. 326 (May 1967) (mimeo.). This fine contribution lists 1220 references, which included 707 which were not in the first 66 pages of this revision. The latter included 324 references not found in the Kennedy and Mihursky contribution from which we have added 338 references as an Addenda starting on page 67.

During the preparation of this edition it was proposed that it appear as a computer print out to include a detailed subject index. Because of various temporary difficulties this has been left for a future edition. Those who receive a copy of this are invited to scrutinize it carefully and pass on their suggestions for additions and corrections.

Our special interest is ichthyology and the emphasis herein has been on fishes. However, some significant papers which have come to our attention which relate to other groups have been included, but obviously it is not complete for these nor for fishes.

This bibliography is weak with regard to foreign coverage except perhaps for those titles which have appeared in English. We have included some documents which have appeared in mimeographed or similar form.

We also have attempted to list abstracts, particularly those which have appeared in Sport Fishing Abstracts. Again, for future editions we would appreciate being informed of other abstracts.

No attempt has been made to include many of the numerous references to temperature conditions of oceans, lakes, and streams.

William H. Massmann and Kirk Strawn made comments on the first edition and furnished additional references.

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