NAKANOUNUMI LAND RECLAMATION AND FRESHENING PROJECT

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ABSTRACT

Lake Nakanoumi is a shallow coastal lagoon connected with the Japan Sea only by a narrow channel. The Nakanoumi Land Reclamation and Freshening Project was started in 1963. The objectives of this project were to reclaim agricultural lands of 25 km² from Lake Nakanoumi and to convert the remaining water basin of some $3.6 \times 10^8$ m³ into a fresh-water reservoir by damming its narrow entrance. However, socio-economic conditions have drastically changed since the late 1960's. The original plan of agriculture in newly reclaimed lands had to be changed because of a rice overproduction since 1967 and the future land-use plan has not yet been determined. It was widely appreciated in the 1970's that a natural environment was indispensable for human life. Under these circumstances local people began to raise cries for reconsideration of the project which seemed to lose its original purpose and significance. Until now the full enclosure of Lake Nakanoumi has not been started, despite the completion of a tidal gate in 1974. An inter-disciplinary approach becomes increasingly more necessary to solve the problem.

KEYWORDS
Land reclamation; environmental impact assessment; brackish-water environment; coastal lagoon; lake ecosystem; hydraulic project.

INTRODUCTION

Coastal lagoons are increasingly used for harbours, recreational areas, their fisheries, etc. However, it is not always recognized that coastal lagoons with poor circulation properties are the most stress-vulnerable ecosystem of coastal water bodies. There exist approximately 62 lagoons in the coastlines of the Japanese Archipelago (Fig. 1). The lagoons are generally fertile and shallow, so that they have provided the opportunities for reclamation of agricultural lands in this densely populated country since early times. Particularly after the Second World War, the government promoted land reclamation works to cope with the food-shortage problem and to provide employment opportunities for the repatriates. Of them the Kojima Bay Project (1947-1963) and the Hachiro-gata Lagoon Project (1957-1977) were the most important works completed at national expense. The important point
point of the projects was that the remaining water basins of Kojima Bay and Hachiro-gata Lagoon were artificially turned into fresh-water reservoirs, mainly to supply newly reclaimed lands with irrigation water. In this respect, it was said that these projects made an epoch in the history of land reclamation works in this country. However, the man-made fresh-water reservoirs recently demonstrate severe eutrophication with occurrences of blooms of a blue-green algae, Microcystis aeruginosa. Although the hydraulic works were planned and almost realized before such environmental problems were fully recognized, the existing circumstances show that many problems are left to be solved with respect to the managerial aspects of coastal fresh-water reservoirs.

The Nakanoumi Land Reclamation and Freshening Project was started in 1963 after the hydraulic works of the Kojima Bay and Hachiro-gata Lagoon Projects had been almost completed. The objectives of this project were to reclaim agricultural lands of 25 km² from Lake Nakanoumi and to convert the remaining water basin into a fresh-water reservoir by damming its narrow entrance. According to the original plan of 1963, Lake Nakanoumi would have been cut off from the Japan Sea by around 1976 and it was expected that the newly constructed reservoir would meet the requirements for the rationalization of farm management and its future development.

However, socio-economic conditions changed drastically in the late 1960's. As a result of government policy to increase rice production, the area devoted to rice cultivation reached 3,400,000 ha in the early 1960's and rice production thus showed a chronic surplus since 1967. The government enacted the Rice Production Curtailment Policy in 1970 and discouraged new formation of paddy fields. According to this policy, the original plan of agriculture in newly reclaimed lands had to be changed and the future land-use plan has not yet been determined. On the other hand it was widely appreciated in the 1970's that a natural environment was indispensable for human life. Man-made alterations of a natural environment required careful consideration in order not to harm natural ecosystems. Under these circumstances local people began to raise cries for reconsideration of the Nakanoumi Project, which seemed to lose its original purpose and significance. Until now, combined with delay in the polder-construction works, the full enclosure of Lake Nakanoumi has not been started despite the completion of a tidal gate in 1974.
The objectives of this paper are to describe the complications of the "Nakanoumi Problem" and to review the inter-disciplinary efforts to solve the problem. Needless to say, the views expressed in this paper are those of the author and not necessarily those of the Ministry of Agriculture, Forestry and Fisheries.

BRACKISH LAKE NAKANOUMI

Location and Morphometry

Lake Nakanoumi is located in the northwestern part of the Japanese Archipelago (ca. 35°30'N Lat and 133°10'E Long). It is connected with the Japan Sea only via the Sakai Channel which is approximately 0.3 km wide and 7.5 km long (Fig. 2). The Yumigahama Peninsula which separates Lake Nakanoumi from the Japan Sea is a large alluvial sand bar formed in Miho Bay. There are two small islets, Daikon-jima (506 ha) and E-jima (96 ha) in the northern part of Lake Nakanoumi. Lake Shinji is located to the west of Lake Nakanoumi and the 7.5-km long Ohashi Channel connects them. Lake Shinji is also linked with the Japan Sea by the Sada-gawa which is a small man-made channel dug in the 18th century. Prior to the reclamation activities, Lake Nakanoumi had a surface area of 97.5 km² and a total storage volume of $5.2 \times 10^8$ m³ at mean water-level of 0.2 m. At present these figures are reduced to 72.5 km² and $3.6 \times 10^8$ m³, respectively. The maximum depth of the lake is 8 m and about 70% of this area is shallower than 7 m.

![Fig. 2. Map of Lakes Nakanoumi and Shinji.](https://iwaponline.com/wst/article-pdf/16/1-2/151/95908/151.pdf)
Hydrology and Hydrochemistry

The annual precipitation recorded at Matsue City is in the range of 1500-2000 mm, averaging 1820 mm during the period of 1966-1979. The catchment area of Lake Nakanoumi is about 573 km² and there are 13 rivers flowing into the lake. The total river inflows are 2.5 x 10⁹ m³/year, of which about 70% is contributed by the outflow from Lake Shinji. The nominal retention time is about 1.6 months at a mean river discharge. The outflow water from Lake Shinji contains salinity of 5-15 ‰ (fresh-water content of 60-90%) so that the total fresh-water inflow is estimated as 1.8-2.3 x 10⁹ m³/year. Tides in the Sakai Channel are semi-diurnal at spring tides but predominantly diurnal at neap tides. The astronomic tides are of small amplitudes, typically about 30 cm at the mouth of the Sakai Channel and they are generally superimposed on longer term changes in water-level of similar amplitudes. Because of the relatively small size of the entrance channel, the tidal amplitude is reduced by 25% in the lake. The ratio of tidal range to time-averaged water depth is approximately 0.03. The mean volume of the tidal prism between MHW and MLW is about 1.52 x 10⁷ m³ (4.2% of the lake volume at MLW) and five times more than that of river inflows during a tidal cycle. Seasonal water-level in Lake Nakanoumi is generally high in summer (35-40 cm) and low in winter (0-5 cm).

Table 1 summarizes the yearly mean values of common water properties measured at the central basin of Lake Nakanoumi in 1979. The annual water temperature range is considerably broad (3-30°C), while the vertical differences between surface and bottom waters range only to the extent of 0-3°C throughout the year. Salinity decreases toward the interior of Lake Nakanoumi from 30-35 ‰ at the Sakai Channel and to 5-10 ‰ at the Ohashi Channel. In the deeper basin of Lake Nakanoumi a halocline develops at the depth of 3-4 m (Ohtake and others, 1980a). Consequently the oxygen content of the bottom waters is remarkably low in summer, despite DO over-saturation in the surface waters. T-P concentration at the central basin of Lake Nakanoumi has a distinct seasonal cycle with quite high values during the summer months, which is tightly connected with release of phosphate-P from bottom sediment (Ohtake and others, 1982a). Recently, possibly because of the lack of a proper public sewer system in urbanized nearshore areas, water quality deterioration has been conspicuous. The summer oxygen content of the bottom waters at the central basin of Lake Nakanoumi has substantially decreased during the past 15 years. Quite high concentrations of T-P and T-N have been recorded in the stagnant water of the Yonago Embayment where a city of approx. 127,000 inhabitants discharges its waste waters.

TABLE 1. Yearly Mean Values of Common Water Properties (1979)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Upper layer (1 m)</th>
<th>Lower layer (5 m)</th>
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</thead>
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<tr>
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<tr>
<td>Chlorinity</td>
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<td>Dissolved Oxygen</td>
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<td>Nitrate-N</td>
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<td>Chlorophyll a</td>
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</table>

Biological Features

Generally speaking the biotic communities of Lake Nakanoumi are composed of a mixture of endemic species and those which come in from the open sea and the fresh-
water environment. On closer investigation, some regional features can be found with respect to the species composition of the communities. Ohtake and others (1980b) reported that a total of 66 phytoplankton species occurred during the period of 1974–1978. The dominant species are the marine and brackish diatoms Skeletonema costatum, Thalassionema nitzschioides and Asterionella japonica, and flagellates like Prorocentrum minimum and Gymnodinium spp. The phytoplankton communities have salient regional features which are closely related with surface salinity distribution (Ohtake and others, 1980c). Green algae were almost confined to the low-salinity region from Lake Shinji to the Ohashi Channel. The percentage of blue-green algae in the total number of phytoplankton cells decreased with increasing salinity. At present the occurrence of the genera Microcystis and Oscillatoria whose blooms cause severe water management problems in many fresh-water lakes are strictly limited to the western part of Lake Shinji. On the contrary, the percentage of diatoms increased with increasing salinity. Flagellates are most abundant at the Yonago Embayment where the water quality deterioration is conspicuous. It should be mentioned that red tides of dinoflagellates have often been observed throughout the Lake Nakanoumi since around 1975.

According to Fukuda (1981), a total of 50 zooplankton species except planktonic larvae has recently been observed in Lake Nakanoumi. The copepode Oithona nana and the ciliate Pavella taraikaensis occur throughout the lake. The copepodes Sinocalanus tenellus, the ciliate Mesodinium rubrum, the rotifer Brachionus plicatilis and the euryhaline fresh-water rotifer Keratella valga are dominant species in the lower-salinity region. On the other hand, the Ciliates Tintinnopsis karajacensis, Tintinnopsis sufflata and the cladocera Podon leuckarti are more abundant in the higher-salinity region. Numerous planktonic larvae are also observed in Lake Nakanoumi and they mainly belong to littoral and brackish species.

Lake Shinji is one of the most important areas for shellfish fisheries in Japan, producing more than 35% of the nation's catch of Japanese marsh clam Corbicula japonica. The main fishing ground is the shallow sandy region in the eastern part of Lake Shinji. Kikuchi (1964) reported that a large number of the cockle Anadara subcrenata as found in Lake Nakanoumi and this cockle was one of the important species in the fisheries. According to the recent studies by Iga (1981), Anadara subcrenata can no longer be observed in Lake Nakanoumi, possibly because of the water quality deterioration. At present a total of 26 species can be observed with respect to the macro-benthic fauna in Lake Nakanoumi. Musculus senhouia, Tapes philippinarum and Macoma incongrua are dominant pelecypods, while Ancistrothecis hanaoka, Nephytys polybranchia, Prionospio japonicus and Prionospio pinnata are important polychaetes. In summer DO concentrations of bottom waters at the central basin of Lake Nakanoumi are generally very low and most of the macro-benthic fauna disappears. Only the polychaete Siganbra tentaculata can barely be observed during the summer months.

A total of 282 fish species (85 families) was recorded in the region from Mibay Bay to Lake Shinji (Kawanabe and others, 1968). Curcian carp Carassius gibelio, pond smelt Hypomusus olidus, common goby Acanthogobius flavimanus, ice fish Salangichthys microdon, sea bass Lateolabrax japonicus and small silvery mackerel Leignonathus nuchalis are important species in the region from the Ohashi Channel to Lake Shinji. Species like Acanthogobius flavimanus, freshwater eel Auguilla japonica, Lateolabrax japonica, bay sardine Harengula zunasi, Leignonathus nuchalis and northern anchovy Engraulis japonica are dominant species in the central basin of Lake Nakanoumi. Harengula zunasi, Lateolabrax japonicus and jack mackerel Trachurus japonicus are common in the Sakai Channel. According to Kawanabe and others (1968), salinity is a main factor controlling the distributions of fish fauna in this area. Fresh-water fish like carp Cyprinus carpio, Carassius gibelio and herbivorous chub Ischikiaua steenackeri are strictly restricted to Lake Shinji and the innermost part of the Yonago Embayment. On the contrary, flathead Platyccephalus indicus Asian pigfish Therapon oxyrhynchus, black porgy Mylio macrocephalus, needlefish Ablennes anastomella, grunnel Enedrias neblosus and surfperch Ditrema temmincki are never observed in Lake Shinji. Trachurus japonicus, Asian croaken
Sillago sihama, Conger eel Conger myriaster and Pacific sardine Sardinops melanosticta are abundant in the Sakai Channel, but they are seldom observed in the central basin of Lake Nakanoumi. However, many fish migrate from the Japan Sea through Lake Nakanoumi to Lake Shinji despite the considerably large salinity differences. It is shown that seasonal variations of water temperature, salinity and DO concentration as well as biological factors including food and feeding habits of fish are major factors causing the migration of fish.

Lake Shinji and Nakanoumi are designated to become a national wildlife sanctuary. From the ornithological point of view, the lakes are of international importance. More than 200 species of waterfowl have been observed in this sanctuary during the past decade (Yamamoto, 1982). Of these wild ducks are most numerous during the period from late autumn to early spring. Tufted duck Aythya fuligula, pochard Aythya ferina, mallard Anas platyrhynchos and wigeon Anas penelope are important species of wild duck. Lake Nakanoumi is an important foraging station for migrant waders. Eastern bewick's swan Cygnus columbianus stay over the winter in Lake Nakanoumi, which is the southern limit of their distribution area in Japan. In late spring snipe and plover come flying to this area. Eastern little stint Calidris ruficollis, eastern dunlin Calidris alpina are numerous species. Other important species are kamchatkan black-headed gull Larus ridibundus and black-tailed gull Larus crassirostris. It should be mentioned that the areas being reclaimed are important nesting grounds for several waders.

Socio-economic Aspects

The areas bordering Lakes Nakanoumi and Shinji have developed as social, cultural and political centers in the northwestern part of Japan. There are more than 350,000 inhabitants in the catchment area of Lake Nakanoumi. The main cities are Matsue (135,000 people), Yonago (127,000), Sakaiminato (37,000) and Yasugi (32,000). Generally speaking the main industries of this district are agriculture, commerce and fisheries, since it is located unconventionally for manufacturing industries. It may be said that, owing to the unfavourable physical conditions, the natural environment has been able to avoid damage due to large-scale development projects as found in the highly industrialized Pacific coast of Japan. Manufacturing areas are located along the southern shore of Lake Nakanoumi. These areas in the artery of traffic are also centers of commerce in this district. Sakaiminato City at the tip of the Yumigahama Peninsula is an important port for offshore fisheries and foreign trade. The possibility of a highway from Sakaiminato City to the Pacific coast of Japan is still being studied.

The farmland totals 11,640 ha or approximately 20% of the catchment area of Lake Nakanoumi. Rice-paddies account for about 80% of the farmland. Important farmlands are located in the Yasugi Plain along the Inashiki River, the Yumigahama Peninsula and the Daikon-jima Islet. Particularly the Yasugi Plain has been the grain belt of this district. The Daikon-jima Islet is famous for its floriculture and ginseng raising, while most of the farmland in the Yumigahama Peninsula is used for truck-farm gardens. Since the water in Lakes Nakanoumi and Shinji contains salinity higher than available for agricultural uses, the greater part of the farmland in this area depends upon small streams for its irrigation water. Particularly the farmland in the Yumigahama Peninsula is irrigated only by the Yonekawa Channel with its source in the Hino River. Consequently it is said that about 10,000 ha of the farmland can be damaged by the shortage of irrigation water in a dry year.

The working population engaging in primary industry was halved and the acreage under cultivation decreased by 14.1% in the past decade. Particularly the areas devoted for rice production have continuously decreased since 1970, because of the Rice Production Curtailment Policy.

As mentioned earlier, the brackish water environment of Lakes Nakanoumi and Shinji is a species-rich coastal ecosystem and has provided the opportunity for extensive fisheries. Particularly Lake Shinji is one of the most important areas for shell-
fish fisheries in Japan. However, after the fishery right was extinguished in 1967 to start the Nakanoumi Project, the number of fishermen working in Lake Nakanoumi has remarkably decreased. In 1967 the fishermen’s union in Lake Shinji also received compensation money for the brackish-water fish species which would disappear after the enclosure of Lake Nakanoumi. Consequently it may be said that the fisheries in Lakes Nakanoumi and Shinji are fated to decline after the completion of the project. The area bordering the lakes has value as a sightseeing resort and a place of natural beauty. Lakes Nakanoumi and Shinji are becoming increasingly major recreational areas. The attractiveness for recreation derives largely from the tranquil water zones. Annually more than one million tourists visit this area from all over the nation.

RECLAMATION AND FRESHENING PROJECT

Historical Background

As early as 1922, the Ohashi Channel was dredged to increase its discharge capacity. It was intended to protect the low-lying area bordering Lake Shinji from flood damage. As a result the difference in water-level between Lakes Nakanoumi and Shinji decreased considerably and the brackish water of Lake Nakanoumi began to enter Lake Shinji which was a fresh-water lake at that time. This led to a great loss of fresh-water in Lake Shinji and the farming in the near-shore areas was threatened with drought and salt damages due to shortage of the irrigation water. Particularly after a severe drought occurred in 1939, the farmers clamoured for retaking their irrigation water from Lake Shinji.

On the other hand both the lakes are fertile and shallow, so that small-scale land reclamation works have been carried out since early times. After the Second World War, the central government promoted land reclamation works to cope with the food-shortage problem and to provide employment opportunities for the repatriates. The Comprehensive National Land Development Act in 1950 was the immediate occasion for the Shimane Prefectural Office to facilitate consideration of regional schemes including river regulation, land reclamation and fresh-water storage in Lakes Nakanoumi and Shinji. The Shimane Prefectural Office repeatedly negotiated with the central government, which alone possessed the necessary capital for such a large-scale development project. Through these efforts the comprehensive development plan for the Nakanoumi Land Reclamation and Freshening Project was drafted in 1954.

Objectives and Outlines of the Project

The objectives of this project are:
1. to reclaim agricultural lands of 25 km² from Lake Nakanoumi and
2. to turn the remaining water basin as well as Lake Shinji into a fresh-water reservoir with an area of 150 km² (Fig. 3).

This project has been carried out under the direct administration of the Ministry of Agriculture, Forestry and Fisheries since 1963. The government at that time had two major objectives in mind: better water economy and expansion of the area devoted for agricultural use. It was expected that the realization of a total of 25 km² of the reclaimed lands would provide the opportunities for large-scale farming which would lead to the rationalization of farm management and the resultant increase in food production. The attempted fresh-water reservoir, when completed, will be capable of supplying the newly reclaimed and existing farmlands of some 75 km² with sufficient irrigation water. Owing to this, the farming in the area bordering the lakes was expected to be freed from a threat of drought and salt damage. In addition, after the Nakanoumi New Industrial Development Program
was started in 1966, it was considered that the reservoir would play an important role in fostering the growth of manufacturing industries in this area.

![Fig. 3. Nakanoumi Land Reclamation and Freshening Project.](image)

**Land reclamation.** Five areas were chosen to be reclaimed (Fig. 3): Honjo (1689 ha), Iya (322 ha), Yasugi (203 ha), Hikona (184 ha) and Yumigahama (144 ha). The former three areas were to be reclaimed by pumping dry, while the latter two areas were to be reclaimed by pumping dry, while the latter two areas were to be filled up. By the reclamation activity, the surface area and storage water volume of Lake Nakanoumi will be reduced down to 72 km² and $3.6 \times 10^8$ m³, respectively. The length of the dikes totals 35.34 km. The method of dike construction was according to that used in The Netherlands. The bottom of the five areas was mostly composed of soft soil including clay, silt and silt loam. In order to reinforce the base of the dikes, most of the soft soil was removed by dredging and replaced by sand and gravel. The sand and gravel for construction of the dikes were obtained using suction dredgers mainly from the Sakai and Nakaura Channels. The width of the dikes has to be as thick as possible to prevent the percolation of water. Taking into account the work operation and economic aspects, the decision was made to build gently slopes levees mainly filled with sand. The roads on the dikes are expected to reduce the distances between different parts of the area bordering Lake Nakanoumi. This connection will contribute much toward the industrial and cultural developments of this district. In particular it should be mentioned that the construction of dikes connecting the Daikon-jima with the Shimane Peninsula remarkably enhanced the economic value of the islet.

**Fresh-water reservoir.** Lake Nakanoumi will be separated from the Japan Sea by the Nakaura-gate (Fig. 4) which was constructed across the entrance channel by 1974. As for Lake Shinji, a small tidal gate is also under construction across the Sadagawa River. The Nakaura-gate has ten drainage sluices each of which is 32 m long and three ship locks near the center of the channel. The ship locks can be used to allow the passage of vessels up to 5000 tons. During ebb tides the sluices are
open to allow an outflow from Lake Nakanoumi, while during flood tides they are closed to block any return of sea water back into the lake. It was predicted that the surface salinity in Lake Nakanoumi would be reduced down to 0.4 o/oo within a year after the beginning of the freshening operation. The water of the resultant reservoir will be used for irrigation by pumping it into the polders by means of power pumps. For this purpose, nine power pumps are being installed at suitable places. The tidal gates will also be used for adjusting and keeping the reservoir water at a suitable level of 40 cm in summer and 10 cm in winter, which is nearly the same as the average tidal level. The surface area of the fresh-water reservoir is 15,000 ha and the water of the reservoir is available for irrigation down to 30 cm below the controlled water-level. The total volume of this available water comes up to $4.4 \times 10^7$ m$^3$. On the other hand the total volume of water needed for newly and existing farmlands is estimated to be $8.0 \times 10^7$ m$^3$/year. This will be in the magnitude of $10^6$ m$^3$/day during an irrigation period or approximately 17% of the inflow fresh-water volume. Consequently it is thought that the volume of irrigation water will be sufficient for keeping the whole of the area properly irrigated even in a drought year. The roughly estimated amount of construction expenses for the entire project was originally 100 million dollars.

Fig. 4. The Nakaura-gate with ten sluices and three ship locks.

Aspects Considered

In the preparation of the project, there were some problems to be studied. Important problems were: flood control, erosion of the Yumigahama Peninsula, seawater intrusion during the lock operation, drainage of low-lying lands and water pollution of the expected reservoir. The former four problems were concerned with the hydraulic aspects of this project and its was not long until solutions were found since much experience had been accumulated through the work on the former Kojima Bay and Hachiro-gata Lagoon Projects. As for water quality problems, local water pollution in the Yonago Embayment was detected and some people feared that the pollution might spread over the whole of the lake. However, it appears that water pollution problems were not fully recognized in the decision-making process. Particularly eutrophication concepts were scarcely known at that time. Attention was exclusively drawn to ensuring that resources were developed in time to meet the future demands. On the other hand, it was recognized that there would be a remarkable decline in the population of brackish-water fauna. The disappearance of the flourishing shellfish fisheries was considered as the most serious drawback of the plan. The commercial fishing in Lake Nakanoumi had to be ended owing to the loss of the shallow areas as nursery grounds and a drastic decrease in salinity. The Shimane Prefectural Office commenced the study on the ecology and production in Lakes Nakanoumi and Shinji to obtain the basic data required for the indemnification with the fishermen's unions. However, the ecological information was not used from the viewpoint of an environmental impact assessment, since no legal obligation was yet assigned with respect to the environmental impact assessment. After the project was started, some environmental problems arose and the government had to deal with the problems in the course of the realization of the project. The following are some features of the initial considerations.
Flood control. As a result of the reclamation activities, the surface area of Lake Nakanoumi was reduced by 25%. In order not to decrease the flood-control capacity of Lake Nakanoumi, the Sakai Channel was enlarged by dredging its bottom down to 10 m. The cross-sectional area of the channel was increased from 2100 m² to 2600 m². The Nakaura Channel across which a tidal gate was constructed was also widened to 400 m and deepened to 7 m. The enlargement works were started at the end of 1968 and completed by 1974.

Prevention of seawater intrusion during the lock operation. Lake Nakanoumi will be fully separated from the Japan Sea by the Nakaura-gate. The drainage sluices were designed to consist of two-stage roller gates. The ship locks must be opened during the passage of vessels and it is unavoidable that seawater flows into the freshwater reservoir so long as a conventional lock-structure is used. To keep seawater intrusion at a minimum, various studies were performed using scale-model tests and computer simulations. When the difference in water-level between inside and outside of the Nakaura-gate is larger than a particular value, the drainage of the reservoir water can be easily done by operating the lower gate utilizing the difference in water pressure. In addition a salt exclusion syphon was provided to naturally exclude the bottom water from the reservoir using the water pressure difference. When no difference between water-levels is available, the power pumps of 1900 mm in diameter installed at the syphon can be used an important point was that a deep area of 1 km² which is called "shiodame" was dredged down to 15 m at the inside of the Nakaura-gate to gather heavier salt-water intruding during the lock operation. The shiodame was designed to make the drainage of the Nakaura-gate efficient. All of the gate operation will be automatically done using an on-line computer system.

Water pollution control. One of the difficult problems is how the water quality of the expected reservoir will be controlled. The catchment area of Lakes Nakanoumi and Shinji totals 2070 km² with more than 480,000 inhabitants. Nevertheless, no sewage treatment system was provided in the area bordering the lakes. Industrial and domestic sewages were discharged into the lakes without any treatment. Due to the lack of the proper sewer system, together with the increase in population, the water quality of the lakes had been gradually deteriorating since around 1965. Due to this situation some people warned that the full enclosure of Lake Nakanoumi would adversely effect the water quality which had already begun to be polluted. However, at that time the pollution-mechanism in the lakes was not clear, and these views could not fully be incorporated into the decision-making process. It should be mentioned that a monthly survey on the water quality was commenced in 1965 prior to the beginning of the reclamation works. This was intended for monitoring water quality changes brought about by the construction work. Since little information was available on what would happen after the completion of the project, the government considered it necessary to observe the water quality before and after the project. The parameters measured were: pH, salinity, DO, COD, NH₄-N, NO₂-N, water temperature, transparency, number of coliform organisms and total number of bacterial cells. Distributions of fauna and flora were not recorded until 1974, since the objectives of the survey were primarily concerned with sanitation and agricultural water supply. The fear of damage due to eutrophication was practically absent.

Course of Realization

In 1963 the Ministry of Agriculture, Forestry and Fisheries set up the Nakanoumi Land Reclamation Work Office which was charged with the duty of preparing plans of action for the work. Between 1963 and 1968 the Nakanoumi Office completed the
necessary legal formalities and finished the indemnification arrangements with the fishermen's unions in Lakes Nakanoumi and Shinji. After the five years of preparation, the construction work began in 1968. The dredging of the Sakai Channel was carried out during the years 1968-1971 to increase the discharge capacity up to 3900 m³/sec. The construction of the Nakaura-gate was started in 1968 and completed in 1974. After the completion of the construction of the tidal gate, the Outflow-water from Lake Shinji began to flow past the central basin of Lake Nakanoumi and to arrive directly at the Nakaura-gate.

The building of polder dikes began in 1968 and was almost completed by 1978. The pumping of the Iya and Yasugi polders (Fig. 5) was carried out during the period of 1975-1976. Filling up Hikona and Yumigahama areas was almost completed by 1981. As for the Honjo polder, the pumping dry has not yet been started despite the completion of the enclosure dikes. The dikes connected between Ohmisaki and

![Fig. 5. Yasugi Polder (203 ha).](image)

Daikon-jima and between Daikon-jima and E-jima were completed in 1978. These dikes are used as the access routes to the islets. This terminated the isolation of these two islets. An experimental farmland was set up in the Iya polder and research is being done in the fields of desalinization, soil maturation, choice of crops and other related aspects. This was intended to form a scientific basis for beginning cultivation in the polders.

The damming of Lake Nakanoumi was achieved by the completion of the Moriyama Dike between the E-jima Islet and the Shimane Peninsula in March 1981. The Sadagawa tidal gate will be completed by 1984. The operation-test of the Nakaura-gate was performed by both manual and computer automatic control in 1981. At the end of the fiscal year 1981, about 70% of the total work was finished.

CRITICISM ON THE ARTIFICIAL DESALINIZATION

Socio-economic Changes

The 1970s were a significant "turning point" in the history of agriculture and nature conservancy in Japan. It was a period which was marked by the "Rice Production Curtailment Policy" and the "Limits to Growth". Part-time farming which had specialized in a single cropping of rice, combined with decreasing per capita consumption of rice, brought about serious surplus problems in the late 1960's. This problem may be explained as follows. Since rice has been the most important single crop in Japanese agriculture, the government enacted the "Rice Control Act" during the Second World War, which is still effective at present in controlling the prices of both producers and consumers. The level of the producer's price has been increased at national expense so that rice producers can obtain the same level income as manufacturing workers. Consequently it was feared that rice over-production might put pressure on the national finance in the near future. In 1970 the
government enacted the "Rice Production Curtailment Policy" to control the rice production by forbidding new formation of paddy fields. According to this policy, the original plan of agriculture in the newly reclaimed lands had to be changed from rice production to truck, flower and dairy farming. However, the market prices of truck and flower farming are generally unstable and a further increase in demand is unlikely to develop. As for milk, a production surplus is now apparent due to the stagnating demand in spite of the still low consumption per capita compared with European countries. For these reasons it became difficult to determine the type of agriculture appropriate to a large-scale farm management and the future land-use plan has not yet been determined.

On the other hand more and more functions of a natural environment for human life has been realized and appreciated since the late 1960's. The year of 1970 was declared as the year of Nature Conservancy. Man-made alterations of a natural environment required careful consideration in order not to harm a natural ecosystem. As a matter of course, a discussion arose about the loss of the unique brackish-water ecosystem by the enclosure of Lake Nakanoumi. In addition there was a fear that the loss of approximately 1200 employees in the fisheries sector would be realized by the completion of the project. The worsening economic situation today made this an important problem. The economic loss of shellfish fisheries was estimated to be more than a hundred million dollars a year. The socio-economic changes did not leave the project untouched.

Progress of Eutrophication

It is said that the water quality in Lake Nakanoumi began to deteriorate around 1965. However, little information is available with respect to the water quality before 1965, and it seems difficult to ascertain whether it is true. Since 1965 monthly routine surveys on the water quality in Lake Nakanoumi have been made by the Ministry of Agriculture, Forestry and Fisheries. According to the survey data, it is clear that the water quality deterioration has been intensified in recent years (Ohtake and others, 1982b). Some striking features are as follows. The summer oxygen content of the bottom water at the central basin of Lake Nakanoumi substantially decreased during the period of 1966-1973 (Fig. 6). After the completion of the Nakaura-gate, seawater with high DO concentration began to enter directly into the bottom of Lake Nakanoumi, but the oxygen content still remains low. Both the T-P and T-N concentrations which have been measured at regular intervals since 1975 show a tendency to increase throughout the lake (Table 2).

![Fig. 6. Changes in summer-mean concentrations of DO in the bottom water at the central basin of Lake Nakanoumi.](https://iwaponline.com/wst/article-pdf/16/1-2/151/95908/151.pdf)
Particularly high concentrations were recorded at the Yonago Embayment. Reflecting the progress of eutrophication, red tides of dinoflagellates have often occurred throughout the lake since around 1975. As early as 1970 the local people began to raise cries for some measures to conserve the water quality in Lakes Nakanoumi and Shinji. In 1970 the "Basic Law for Environmental Pollution Control" was enacted and an environmental pollution was more and more recognized to be a severe problem all over the country. In addition the Shimane Prefectural Office commenced about that time a study on utilizing a

**TABLE 2. Yearly Changes in T-P and T-N Concentrations**

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<td>34.1</td>
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<td>458</td>
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* measured at the central basin of Lake Nakanoumi

part of the newly reclaimed lands for industrial purposes and this unavoidably caused apprehension as to the water pollution after the full enclosure of Lake Nakanoumi.

Under these conditions the Shimane Prefectural Office asserted that the water quality deterioration was caused by municipal wastewaters discharged without any treatment and the expected reservoir could be preserved by constructing a proper public sewer system in the areas bordering the lakes. The Shimane Prefectural Office also promised to petition the central government for an environmental impact assessment of the full enclosure of Lake Nakanoumi as early as possible. Since the Nakanoumi Project was begun prior to the Basic Law for Environmental Pollution Control, the environmental impact assessment had not yet been sufficiently conducted up to that time. In 1973 a master plan was drafted to construct a public sewer system in the areas bordering Lakes Nakanoumi and Shinji. However, it should be mentioned that the decision was made to build a secondary treatment plant in a nearshore area of Lake Nakanoumi and to discharge its effluent into the western part of the lake.

Granting the petition from the Shimane Prefectural Office, the Nakanoumi Freshening Impact Research Committee was instituted by the Environment Agency of Japan in 1974. The committee was composed of nine specialists in the fields of hydraulic engineering, microbiology, limnology and aquatic biology. The report of the Impact Research Committee appeared in September 1975. The important point was that even if the sewage treatment system under construction was completed, there was a fear of progress of eutrophication due to the effluents rich in nutrients. However, available data were still limited with respect to the impact of the full enclosure, and the recommendation was no more than an indication that further detailed research was necessary. With this recommendation in view, the Nakanoumi Water Pollution Control Conference was inaugurated by the Shimane and Tottori Prefectural Offices and the related municipalities in 1976. The conference was charged with the duty to monitor the water quality in Lakes Nakanoumi and Shinji and to study measures to control the progress of eutrophication. It was beyond the capability for local governments to assess independently the environmental impact

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of the project. The attention is now being focussed on the Ecosystem Change Research Committee instituted in 1980 by the Ministry of Agriculture, Forestry and Fisheries.

Arguments Against the Project

The arguments against the project are primarily concerned with the loss of the unique ecosystem and the progress of eutrophication. A summary of criticism from civilians may be listed as follows:

1. The brackish-water environment of Lakes Nakanoumi and Shinji have allowed the development of a species-rich coastal ecosystem and provided the opportunity for extensive shellfish fisheries. The fishery right in Lake Nakanoumi was extinguished in 1967 and the fishermen's union in Lake Shinji received the indemnification money for brackish-water species which would disappear after the completion of the project. At that time it was intended to develop the local economics by large-scale farming in polder lands and the decision was made at the cost of the commercial fisheries. However, fifteen years have passed since the original plan was proposed in 1963. The socio-economic conditions have considerably changed from that time. The economic loss of shellfish fisheries is now estimated to be more than one million dollars per year and it seems difficult to compensate the economic loss by farming in polders under the Rice Production Curtailment Policy. The economic costs and benefits of the project should be reassessed under the present conditions.

2. Lakes Nakanoumi and Shinji are also important foraging stations for migrant waders from late autumn to early spring. Both the lakes were designated as a national wild life sanctuary in 1974. Furthermore they are of much value as recreational areas and sight-seeing resorts. The reclaimed lands might be an intrusion on an attractive landscape. Recently more and more functions of a natural environment for human life have been appreciated. People learned to estimate the value of the unique brackish-water environment. Its irreplaceable nature should be left as much as possible.

3. Under the Rice Production Curtailment Policy, it is forbidden to use newly reclaimed areas for rice production. The water-use plan which intended to ensure the irrigation water for rice production has practically lost its original purpose and significance. Admittedly the full enclosure of Lake Nakanoumi will cause the greatest effect on the brackish-water environment. Consequently it is unwise to force the full enclosure of Lake Nakanoumi according to the original plan.

4. Turning to the eutrophication problem, Kojima Bay and Hachiro-gata Lagoon which were converted into fresh-water reservoirs now demonstrate severe eutrophication with nuisance blooms of a blue-green algae Microcystis aeruginosa. In the summer of 1981 a bloom of Microcystis aeruginosa occurred in the low-salinity region of Lake Shinji. Limnologists warned that the decrease in salinity, combined with the ever-increasing load of inorganic nutrients would lead to a favourable condition for the growth of Microcystis species. Preventative measures must be established before the full enclosure of Lake Nakanoumi.

5. From the ecological point of view, it can be said that coastal lagoons with poor circulation properties are delicate and stress-vulnerable ecosystems. The damming of the entrance channel of Lake Nakanoumi will increase the sedimentation rate of pollutants and accumulate them without washing out by tidal currents. The disturbed ecosystem will need a long period for re-establishing the stable condition and during the time the pollution-removal capacity will remarkably reduced.

6. The water quality in Lakes Nakanoumi and Shinji has already deteriorated. In addition, the expected reservoir will receive agricultural wastewaters rich in nutrients from polder lands. This will accelerate the progress of eutrophication of the fresh-water reservoir. Nevertheless, effective measures have not
yet been established with respect to controlling the progress of eutrophication. Although a public sewer system is now under construction, the secondary wastewaster treatment will be ineffective for controlling the eutrophication. The establishment of pollution-control measures should be done prior to the full enclosure of Lake Nakanoumi.

It is clear that these arguments are backed by recent economic changes and the better understanding of the natural environment.

PURSUIT OF CONSENSUS

Lively Discussion about the Full Enclosure

In order to remove apprehensions about environmental problems which might be brought about by the project, the Nakanoumi Office has repeatedly asserted that the water quality deterioration by the project would be avoidable. The grounds of the argument are as follows.
1. By the land reclamation works, the surface area of Lake Nakanoumi decreased by 25% and this led to a reduction of the retention time of water in the lake. The areas with sluggish water movement were eliminated.
2. A halocline usually develops at a depth of 3-4 m in the central basin of Lake Nakanoumi. Due to the inhibition of vertical mixing, anoxic conditions occur in summer. The condition in turn stimulates the release of nutrients from bottom sediment and kills most of the benthic fauna by the production of toxic hydrogen sulphide. Since the stable halocline will disappear after the completion of the project, such an anoxic condition will be remarkably improved.
3. Using the two-stage roller gates and a salt-exclusion syphon which are equipped at the Nakaura-gate, it will be possible to release selectively bottom waters with lower DO and higher nutrient concentrations.
4. At present T-P and T-N concentrations in Lakes Nakanoumi and Shinji are considerably lower than those in the former Kojima Bay. It is unlikely that a large-scale bloom of blue-green algae will occur as in the former lagoons.
5. There exists the 7.5-km long Sakai Channel between Lake Nakanoumi and the Japan Sea. The tidal amplitude of the Japan Sea is considerably small in the magnitude of 30 cm. No direct exchange of water between the Japan Sea and Lake Nakanoumi occurs within a tidal cycle and it is thought that the tidal exchange is of minor importance with respect to the pollution-removal mechanism in Lake Nakanoumi.
6. To control the eutrophication in Lake Nakanoumi, it is imperative to eliminate nutrient loadings from the areas bordering the lake. The impact of the project should be discussed separate from the eutrophication problem caused by nutrient loadings, since the eutrophication has been intensified regardless of whether the project is executed or not.
7. Although the former lagoons now demonstrate severe eutrophication (Fig. 7), they differ from Lakes Nakanoumi and Shinji with respect to the natural and social conditions. It is questionable to directly apply the environmental consequences to the case of Lakes Nakanoumi and Shinji.

On the other hand the contradictions are given as follows:
1. Cutting off the free connection with the open sea will rather increase the retention time of water, particularly during a low-precipitation period when the water quality management will be extremely difficult.
2. Shallow eutrophic reservoirs have an effective recycling of nutrients between bottom sediment and water. It is reported that a vigorous release of nutrients from bottom sediment occurs even in shallow eutrophic lakes (Fukuhara, Tanaka and Nakajima, 1981).
3. No reliable data with respect to the possibility of pollution-removal due to gate-operations have been presented. It should be tested at the heavily polluted Kojima Bay whether the gate-operations will surely be effective for pollution-control.

4. It is unwise to conclude to what extent blooms of blue-green algae will occur based on the present nutrient levels of Lakes Nakanoumi and Shinji, since the concentrations of nitrogen and phosphorus tend to increase in the lakes. The growth of blue-green algae is now strongly limited by the salinity existing in the brackish-water environment.

![Fig. 7. The former Kojima Bay which was turned into a fresh-water reservoir in 1962.](image)

5. The tidal prism in Lake Nakanoumi is estimated as $1.52 \times 10^7$ m$^3$ and five times more than river inflows during a tidal cycle. The role of tides is rather important with respect to the pollution-removal mechanism in this shallow coastal lagoon.

6. The secondary treatment effluent will be discharged into the western part of Lake Nakanoumi. As a result the expected reservoir will unavoidably suffer from eutrophication problems. It is impossible to discuss the impact of the project apart from the progress of eutrophication.

7. The freshened reservoirs now demonstrate water quality deterioration. It is necessary to study why the environmental pollution was caused by the enclosure and to learn some lessons from environmental consequences after the completion of the projects.

**Ecosystem Change Research Committee**

The discussion about the full enclosure of Lake Nakanoumi is now escalating and "the Nakanoumi problem" tends to attract national interest through mass communication. With the aim of minimizing the impact of the project, the government had constituted research committees at some stages of realization of the project. However, in the author's opinion, the government seems to have lacked the flexibility to cope with the changes in the socio-economic conditions after the beginning of the project. In this connection it appears meaningful to briefly review the scientific aspects of the realization of the project.

In 1965 the Hydraulic Committee was instituted to study hydraulic problems caused by the construction works. The committee was composed of nine experts in civil engineering. At that time important problems were: flood control, seawater intrusion during the lock operation and drainage of low-lying areas. However, water quality problems were scarcely discussed. The Water Management Research Committee was instituted in place of the Hydraulic Committee in 1973. The instruction was to study the optimum way of water management including water quality control of the
expected reservoir. For this purpose, a few limnologists and biologists took part in the committee. The committee recommended that a reduction of nutrient loadings was of most importance for water quality conservation during and after the project.

In 1980 the Water Management and Ecosystem Change Research Committee was constituted to assess the ecological impacts and incorporate ecological aspects into the managerial programs. The important point was that the new committee attached importance to a dialogue and cooperation between civil engineers and ecologists. The committee counted specialists in the field of hydraulic engineering, hydrochemistry, microbiology, botany and aquatic zoology. Originally the committee was not charged with the duty of making recommendations on the environmental impact of the full enclosure of Lakes Nakanoumi and Shinji. After the discussion was escalated, the environmental impact assessment was considered to be the most important task of the committee. Actually it can be said that the allowance of the full enclosure depends on the recommendation. However, the methodology which ensures a close cooperation between civil engineers and ecologists has not yet been established, and it appears that difficulties are being felt in the inter-disciplinary approach to the impact assessment. Engineering issues can usually be presented in concise manner with reasonably firm estimates of costs, but ecological factors are generally more difficult to quantify, often impossible to cost and consequently require subjective judgments. Nevertheless, the recommendation must be made on a balance of engineering and ecological factors. The report of the committee would have appeared in June 1982, but it is unlikely that the report will be open before the end of March in 1983.

Proposals for Tentative Desalinization

While it is clear that a quicker salinity reduction has a larger negative effect on the present brackish-water environment, the knowledge on the environmental impact due to artificial desalinization is still vague because of the lack of appropriate information. In 1981 the Ministry of Agriculture, Forestry and Fisheries proposed a plan to begin the desalinization of Lakes Nakanoumi and Shinji in a tentative way. Although the details of the test procedures have not yet been published, the objective of the trial is to gather full information on environmental impacts which might be brought about by the desalinization of Lake Nakanoumi. For this purpose, it is proposed that the salinity will be gradually decreased extending over a period of several years and the environmental changes will be monitored from various angles. The test procedures are now being investigated by the Ecosystem Change Research Committee and will be published together with the conclusion on the impact assessment of the project. It appears that the trial also intends to confirm whether the forecast on the ecosystem changes will be really correct prior to the start of the full enclosure of Lakes Nakanoumi and Shinji. It is scheduled to commence the trial after obtaining a concurrence from Shimane Prefectural Office and the related municipalities based on the recommendation of the committee.

Needless to say, close attention must be paid to avoiding a drastic change in the lake ecosystem and in case some abnormal conditions occur during the period of the trial, sluice gates of the Nakaura-gate must be opened to restore the lake to the former state. However, ecological changes generally occur slowly and it is difficult to quantify the changes within a short period of time. There is still a risk that unforeseen ecological changes will take place after the full enclosure of Lakes Nakanoumi en Shinji. Taking into account the damage of the brackish-water ecosystem, it seems still difficult to achieve a consensus by this proposal under the escalating discussion about the significance of the full enclosure.
CONCLUSIONS

Work on the project has lasted 15 years since 1968. This is much longer than was expected. The total expense of the project is now estimated at more than 250 million dollars. According to the original plan of 1963, the Nakanoumi project would have been completed by around 1976. Since the construction work of polders and tidal gates is expensive, the delay of the work in mainly due to financial reasons under the worsening economic conditions. However, it is undeniable that the project was affected by a better pressure from the public for assessment with a mind to the remarkable change in socio-economic conditions during the past decade. Gaining public acceptance is now a major problem for the Ministry of Agriculture, Forestry and Fisheries. Lakes Nakanoumi and Shinji are an irreplaceable natural environment which has supported the culture and society in this district. They are closely tied in with the industries and living of the local people. For these reasons it is understandable that the local people demand acceptable measures for conserving the beautiful and rich environment.

A large-scale hydraulic project generally requires a prolonged period of time and hence necessitates constant course corrections. It is imperative at each stage of realization to leave room for adjusting to a change in the future. In this connection, reclamation works in The Netherlands exemplify the careful planning procedures. In the Zuiderzee project the construction works were planned to follow a sequence in which experience, manpower and equipment could be used to best effect (Knights, 1979). Admittedly a complex organization lacks the flexibility to cope with socio-economic change. It is desirable that a single authority with power covering the multi-faceted work is set up to run the project most efficiently. Otherwise even if a reconsideration is highly reasonable, it is hard to consult the public on some alternatives. In this respect it seems necessary to learn from foreign experience (Parma, 1978).

The natural environment of Lakes Nakanoumi and Shinji has been damaged by a variety of human activities. In the summer of 1981 blooms of blue-green algae Microcystis aeruginosa occurred in Lake Shinji. Reclaimed lands are an intrusion on the attractive landscape and construction works are harming the nesting ground for waders. It should be recognized that coastal lagoons are stress-vulnerable ecosystems and a development adjacent to such an environment will require an exceptionally vigorous management. In the worst case there is a fear that the expected reservoir would be heavily damaged by the progress of eutrophication. A thorough check on the environmental impact of the full enclosure of Lake Nakanoumi...
is urgently needed. Important points are:
1. lessons from environmental consequences in the former Hachiro-gata Lagoon and Kojima Bay,
2. preventive measures on blooms of blue-green algae,
3. reduction of nutrient loadings from the surrounding areas,
4. water quality control during a low-precipitation period and
5. evaluation of the self-purification capacity of the lake ecosystem.

It is urgently necessary to establish a methodology to ensure a close cooperation between civil engineers and ecologists in the field of environmental science. Newly reclaimed areas of 25 km² are obtained at the expense of a valuable natural environment. They must be utilized most efficiently. There is a great demand for land in this densely populated country. Many reclaimed lands have already been converted to areas for non-agricultural use. On the contrary, some areas reclaimed for agricultural purposes are still unused under the Rice Production Curtailment Policy. The allocation of the reclaimed lands is an important issue. It appears that pumping dry of the Honjo polder should be delayed until a master land-use plan is established and tests necessitated for agriculture are conducted using the Iya and Yasugi Polders. Lakes Nakanoumi and Shinji are designated a national sanctuary for wildlife. The land-use plan should be determined as to be harmonious with the surrounding environment. Wastewaters discharged from reclaimed lands must be treated using available techniques.

The volume of fresh-water demanded for agricultural use is estimated as only 3% of the total input of 2.5 x 10⁹ m³/year. It appears necessary to reassess water demand to know whether the full enclosure of Lakes Nakanoumi and Shinji is even now unavoidable. Admittedly the full enclosure has the largest impact on the brackish-water environment. It is hard to prevent the enclosed reservoir from damages caused by wastewater inflows. One possible solution is to build a bunded reservoir as is being investigated in the United Kingdom (Taylor, 1981). This has an advantage of greater control of water quality taken into storage and is likely to match the growth of demand.

From man's viewpoint coastal lagoons must always be considered as a multiple use environment (Odum, 1971). It seems unwise to use it only for agricultural use at the expense of other utilization. The multiple use of the environment may include agriculture, fisheries, manufacturing industries, sight-seeing resorts, recreation and transportation. In this connection the economic effects of the project should be reassessed under the present conditions.
It is reasonable that the government fears an unacceptable delay of the project. However, successful measures are only assured when they can obtain cooperation from the public.

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REFERENCES


