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Dickey-Lincoln School Lakes Hydroelectric Project : Summary of Water Quality Factors

New England Division

U.S. Army Corps of Engineers

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DICKEY-LINCOLN SCHOOL LAKES HYDROELECTRIC PROJECT

SUMMARY OF WATER QUALITY FACTORS

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g prepared.)

4.05 Water Quality

The prediction of future water quality conditions in and downstream from a proposed impoundment is dependent upon a myriad of physical, chemical and biological phenomena. It is known from limnology (science of lakes) that all physicochemical and biological functions are greatly controlled or influenced by lake hydrodynamics, lake thermodynamics, and the quality of inflowing water.

To make the predictions that follow for the Dickey-Lincoln School Lakes system, extensive physical and mathematical model investigations of the hydrodynamic and thermal stratification characteristics of the tandem lakes were made and baseline water quality surveys in the contributing watershed of the Saint John River were conducted. The results of these investigations and surveys are presented in detail in Design Memorandum No. 5, Water Quality, USCE.

4.05.1 Reservoir Water Quality

4.05.1.1 Dickey Lake

Construction of the project would create two impoundments, Dickey and Lincoln School Lakes. Dickey Lake would have a dendritic shape with three major arms, namely the Saint John River, the Little Black River, and the Big Black River. Its maximum depth would be 325 feet near the dam, the mean depth would be 78 feet, full pool volume would be 7.7 million acre-feet and the detention time would be 2-3 years. Lincoln School Lake would be an elongate impoundment with no major arms, and would have a full pool volume of 86,000 acre-feet and a maximum detention time of several weeks. The Lake's maximum depth would be 80 feet; its mean depth would be 33 feet.

As a consequence of the project, the existing terrestrial environment in the project area would be converted to an aquatic enivornment through inundation. A number of physical and chemical changes in water quality would occur, especially in Dickey Lake with its long detention time. Factors that would influence reservoir water quality include basin climatology and hydrology, reservoir clearing practices, thermal stratification, morphometric characteristics, and inflow quality. The primary factors that would influence water quality in Lincoln School Lake are the quality of the water released from Dickey Lake and the quality of inflows from the Allagash River. Differences would occur in Dickey Lake between the quality of water in the coves at tributary inflow points and that of the main body along the Saint John River arm. Lincoln School Lake would be totally mixed with homogeneous quality conditions.

Dickey Lake would exhibit temperature-induced density stratification as a result of meteorological influences. The temperature regimen of the lake with both initial and ultimate power development was simulated for a wide range of hydrologic and meteorologic conditions using a mathematical model which incorporated the specific hydrodynamic characteristics of the Dickey-Lincoln School Lakes system. The temperature simulations indicate that the strongest stratification conditions would exist in mid-summer when temperature differences as large as 68°F (20°C) would exist between the surface and bottom waters. The temperature of the lower 200 to 250 feet of the lake would remain near 4°C throughout the year, while mid-summer surface temperatures would range from 57°F-75°F (14 to 24°C). The location of the thermocline would vary from 5 feet to 45 feet below the surface, depending on daily atmospheric conditions and time of year; the thermocline would be depressed through the fall season as a result of surface cooling. Simulated temperature profiles representing the most wide range of conditions on August 15th from six historical years studied in the temperature regimen analysis are presented on figure 4.05-1.

During the filling period of Dickey Lake, biogenic meromixis, a condition of biochemically induced chemical stratification that prevents complete mixing of a lake, could develop. Initiation of pumpback operations immediately after filling would destroy any such condition, and the lake would then become dimictic and holomictic, meaning that it would experience two turnover periods per year (spring and fall) and the turnover would encompass the entire depth of the lake. Following the fall circulation period, an ice cover would form and would last until the following spring. With the ice cover providing insulation, the lake would exhibit a reverse stratification pattern owing to the fact that water has its maximum density at 39°F (4°C) and is less dense at colder temperatures. Temperatures would range from 32°F (0°C) at the surface, through a zone of increasing temperature, to as high as 39°F (4°C) in the major portion of the lake's depth. The actual temperature regimen would be influenced by the degree of wind-induced circulation experienced prior to ice formation, the date of ice formation, the thickness of the ice cover and the amount of heat transfer through the mud-water interface of the lake bottom. As a consequence of winter stratification, the temperature of outflows from Dickey Lake will be several degrees warmer than natural conditions; normally the Saint John River freezes over in the winter. This effect would be transferred downstream to Lincoln School Lake, and perhaps, below Lincoln School Lake to the Saint John River.

Dissolved oxygen concentrations would be near 100 percent of saturation in the upper portion of the lake and at or above 6 mg/l in the lower portion at the end of the summer stratification period. The low bottom temperature would tend to reduce biological and chemical consumption of oxygen. The circulation periods would be of sufficient duration to satisfy the oxygen demand of the bottom waters and maintain a high dissolved oxygen level through transfer at the air-water interface. Some shallow coves may exhibit dissolved oxygen concentrations approaching 2 mg/l during the summer due to warmer bottom temperatures and associated greater biological activity, and due to the morphometry of the cove bottom.

Dickey Lake would have a 96 to 98 percent sediment trapping efficiency because of its long detention time. Coarse-grained particles (bed load) would be deposited rapidly near each inflow point, while finer material (suspended sediment) would be transported farther out to other portions of the coves and arms of the lake before being deposited. Only the most finely grained sediments in colloidal suspension would pass through the lake and be discharged downstream. Daily suspended sediment discharge data were collected by the USGS at the streamflow gaging station on the Saint John River

Dickey Lake would tend toward a concentration order (decreasing) of bicarbonates, sulfates and chlorides. The cation composition would tend toward an order (decreasing) of calcium, sodium, magnesium and potassium. These orders parallel the concentrations of the constituents observed in the surface waters of the watershed during the baseline water quality survey.

The most important heavy metal from an environmental health standpoint that would be present in Dickey Lake is mercury. Mercury has been observed in the watershed in erratic, and sometimes high levels. Sediments will carry a significant portion of the mercury entering the lake through adsorption. Suspended material has a greater adsorptive capacity than coarser bed load material and would tend to carry the mercury to the deeper portions of the lake before deposition occurs. During circulation periods, mercury in the lake would be distributed throughout the water column and would become available for biological uptake. During stratification periods, much of the mercury would precipitate to the lake bottom, some of which would be buried in the bottom sediments and would be lost to further resuspension. The cold temperatures of the lake bottom would not favor the conversion of mercury compounds to mercuric ions or their subsequent methylation. The greatest biological methylation would occur during the spring circulation period and during the early stages of stratification development.

Nutrients would be introduced into the lake by tributary inflows, sediments, precipitation and leaching from the inundated soils and vegetation. Predictions of the natural loadings of nitrogen at Dickey for the period October 1975 through September 1976. This data disclosed a suspended sediment load of 36.5 tons per square mile per year. The bed load portion of the total sediment load was assumed to be equal to the suspended sediment load. Using these loading rates, it was determined that 0.13 percent of the total volume of the lake would be lost due to sediment accumulation in 100 years.

The true color of Dickey Lake would depend on the amount of dissolved solids in the water column. The main determinant, in this case, is dissolved organic matter. Prior to stabilization, the lake would progress from yellowish-brown, the color produced by pure organic matter, to greenish-yellow. When stabilized, the surface waters would vary seasonally at different lake locations from greenish-yellow to greenish-blue. The true color should not interfere with post-stabilization phytoplankton productivity. The apparent color of the lake would be influenced by the amount of suspended material present and, therefore, would vary seasonally depending upon stratification, mixing, hydrologic conditions and the amount of aquatic biota present. Color would increase with depth during summer stratification with maxima occurring in the area of the thermocline due to a complex stratification of algae, bacteria and colloidal and dissolved materials.

The ionic composition of Dickey Lake would depend upon the constituent loadings from precipitation and the biogeochemical processes of the watershed and the lake. The anion composition of and phosphorus from the Watershed and precipitation lead to the conclusion that Dickey Lake would be a phosphorus limited, oligotrophic water body. Leaching from the soils and vegetation would be greatest during the filling stage and for several years after until chemical stability is achieved. Nutrient levels in the lake would be sufficient to support the growth of phytoplankton in the photic zone.

Reservoir clearing practices would influence lake water quality, especially during the reservoir filling phase and during the period prior to the achievement of chemical stability. The greatest impacts would result from the leaching of nutrients from inundated soils and vegetation and the decomposition of organic material. These occurrences would cause short term enrichment of the lake and an anaerobic condition in the lake bottom. The releasing of water from the bottom of the lake through the diversion tunnel during filling would withdraw some of the nutrients and organics from the lake, thereby causing a short term effect downstream. Water temperature would be the major factor controlling leaching and decomposition rates. As the lake fills and thermal stratification develops, colder water at the bottom of the lake would bring about a reduction in these rates. In six to nine years after filling, the initial mass of organic substances is expected to stabilize and Dickey Lake would reach chemical stability.

Nitrogen supersaturation is expected to occur in Dickey Lake as a result of natural limnological processes. During the spring circulation period, dissolved nitrogen would be in equilibrium with the atmosphere at 100 percent of saturation. If, with the onset of thermal stratification, the rate of warming of the surface layers of the lake exceeds the rate of nitrogen gas loss, nitrogen in the zone below the influence of thermal circulation and wind mixing will supersaturate as a consequence of the hydrostatic pressure. The major portion of the water withdrawn from the lake would come from the supersaturated zone, therefore the waters entering Lincoln School Lake would also be supersaturated. The effect of the pumpback current upon nitrogen levels in Dickey Lake is not quantifiable, however, it is expected to have a moderating effect in the area of the lake near the dam and thus on the nitrogen levels of discharges into Lincoln School Lake.

Nitrogen supersaturation resulting from the normal operation of the water control facilities at Dickey Lake would not occur. Spillway operations at dams in the northwest portion of the country have been identified as causing nitrogen supersaturation. These spillways are of the operating type and discharge great quantities of water frequently and for long durations. Large quantities of air are entrained by the flow over the spillway, and, as the flow descends into the deep plunge pool of the downstream stilling basin, high hydrostatic pressure causes the air to go into solution, resulting in a nitrogen supersaturation condition. The spillway at Dickey Lake, however, would be of the emergency rather than operating type and would discharge very infrequently (time interval between events is measured in years). There is no evidence that the other water control facilities at Dickey Lake (the turbines and diversion tunnels) would contribute to any nitrogen supersaturation.

Coliform bacteria levels introduced to Dickey Lake at the inflow points are expected to fluctuate as observed during the baseline water quality survey. The lake is expected to display the typical characteristics of other artificial impoundments by effecting a significant reduction in bacterial levels during storage. Open water levels would be lower than those of the coves affected by the littoral influences of the shoreline and tributary streams.

4.05.1.2 Lincoln School Lake

Lincoln School Lake, because of its short detention time and large flow-through volume, would have the flow characteristics of a run-of-the-river impoundment. The results of a physical hydraulic model study of the lake indicate that it would be totally mixed. Conditions in the lake would be further complicated by the fact that water would be withdrawn from it at two locations; discharges would be made through the outlet facilities at Lincoln School Dam and water would be pumped back into Dickey Lake from the upstream end. Discharges from Dickey Lake would have the greatest influence on water quality conditions in Lincoln School Lake because of the large volume of the inflows over short durations. The natural flows of the Allagash River would be another major source of water to the lake.

Water temperatures in the lake would be uniform with depth (isothermal) and would be influenced by the temperature of inflows from Dickey Lake and the Allagash River and by climatic conditions. Significant warming of the cool outflows from Dickey Lake would occur in Lincoln School Lake. The temperature of outflows from Lincoln School Lake will be the mixed in-lake temperature. The possibility exists that small vertical temperature variations may develop during periods when discharges are not being made from Dickey Lake. However, such weak stratification development is expected to be destroyed with the next inflow period. Warm winter outflow temperatures from Dickey Lake coupled with the dynamic nature of Lincoln School Lake could result in warmer than natural outflow temperatures and perhaps the prevention of an ice cover on the lake.

Dissolved oxygen concentrations in Lincoln School Lake would be greatly influenced by Dickey Lake outflows. These discharges are expected to have dissolved oxygen concentrations ranging from 60 to near 100 percent of saturation. Mixing and atmospheric aeration in the isothermal lake are expected to maintain dissolved oxygen within this range of concentrations.

The entire Lincoln School Lake area will be cleared of woody vegetation. Filling of the lake will be accomplished over a very short period of time ranging from a few days to a few weeks, depending on the time of year and coincident operations at Dickey Lake. Because of the short filling time and dynamic operation of the lake, water quality changes due to leaching from the inundated soils and decomposing vegetation would be transferred downstream from the lake through the outflows.

Outflows from Dickey Lake may be supersaturated with nitrogen as a result of naturally occurring, in-lake phenomena. Turbulent mixing and the isothermal conditions within Lincoln School Lake should decrease the dissolved nitrogen concentrations. Lincoln School Lake would have an operating spillway that would discharge more frequently than the Dickey Lake spillway. Steps would be taken to mitigate against any nitrogen supersaturation problem through the exercise of appropriate hydraulic design procedures, such as design of a shallow rather than deep stilling basin.

The major source of sediments to the lake will be the Allagash River since Dickey Lake will greatly reduce the load from the Saint John River. The dynamic nature of the lake should not be conducive to sediment accumulation, and no problems are expected.

Mercury concentrations are not expected to exceed natural conditions. Other physicochemical characteristics of the lake will be primarily a function of inflows from Dickey Lake and, to a lesser degree, from the Allagash River.

4.05.2 Downstream Water Quality

The quality of the waters of the Saint John River below the project site would be affected by the construction and operation of the project. Short to intermediate-term effects could be caused by erosion during construction. Some material could be washed into the river despite the employment of mitigation methods. The result would be increased dissolved and suspended sediment with associated increases in the values of specific electrical conductance and turbidity, and an increase in the bed load portion of the total sediment load. These effects would occur during rainfall-runoff events and are expected to be of a magnitude similar to that which occurs presently from the disturbed portions of the watershed.

Short-term nutrient enrichment could occur as a result of reservoir clearing and filling activities. Waters expected to have somewhat higher than normal nutrient levels would be released from Dickey Lake throughout the duration of these activities. Lincoln School Lake will have a short detention time and, consequently, will pass downstream the enriched waters from Dickey plus the nutrients leached from the lake bottom soils and vegetation.

The impact of the project on downstream water temperatures with both initial and ultimate power development was evaluated with the use of a mathematical reservoir temperature model. The model was used to predict the temperature regimens of the two lakes and their respective outflow temperatures for six years representing a wide range of experienced hydrologic and meteorologic conditions considered to be indicative of expected future conditions. The outflow temperature from Lincoln School Lake was then compared against a band of water temperatures representing the range that naturally occurs within the Saint John River below Lincoln School Dam. The results of this analysis showed that the daily average outflow temperatures from Dickey Lake would be much cooler than natural while those from Lincoln School Lake would be consistently near the lower curve of natural conditions. The results of these simulations for the two years exhibiting the greatest difference in outflow temperatures are presented in figures 2 and 3.

As a consequence of the construction and operation of the project, the temperature regime of the Saint John River immediately below the Lincoln School Dam would be much cooler than that experienced in the past with summertime average temperatures 5°F - 11°F (3°C-6°C) cooler in the six study years. In addition, the range of temperatures to be expected would be much more narrow. Natural summertime water temperatures fall within a 20°F (11°C) band whereas post-project temperatures are expected to fall within a 9°F (5°C) band. Temperatures would change with distance downstream from the project as the water adjusts towards equilibrium with atmospheric conditions. The rate at which the water gains or loses heat along a stream varies inversely with the flowrate. Because outflow rates from Lincoln School Lake within each day will range from a base flow condition of 1,000 cfs to a power generation flow of 16,000 cfs, it is possible that fluctuations in temperature may be experienced for an indeterminable distance downstream over the course of a day. These variations would depend on the flow rate and temperature, time of day and ambient conditions.

Winter time outflows from Lincoln School Lake would be warmer than natural river conditions. This could result in the prevention of ice formation on the Saint John River below the project.

The extent of such a condition would depend on the rate and temperature of the outflow and the climatic conditions.

The sediment load in the river would be reduced because of the high trapping efficiency of Dickey Lake. The major portion of the remaining sediment load would be that portion contributed by the Allagash River which does not settle out in Lincoln School Lake.

Dissolved oxygen levels are expected to range from 60 to 100 percent of saturation, depending on the degree of aeration effected by the Lincoln School Dam outlet works. Nitrogen supersaturation conditions are not expected to result from the operation of the Lincoln School Lake project.

All other physicochemical parameters in the Saint John River below the project would correlate with their levels in Lincoln School Lake.