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New Meadows Lake Tidal Restoration Feasibility Study

Woodlot Alternatives, Inc.

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FINAL REPORT

NEW MEADOWS LAKE TIDAL RESTORATION FEASIBILITY STUDY CASCO BAY ESTUARY PARTNERSHIP

June 2006



New Meadows River from State Road Causeway, July 2005

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Council on the
Marine Environment

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Executive Summary

New Meadows Lake experienced a loss of intertidal habitat and diminished water quality resulting in part from the construction of three causeways across the upper New Meadows River which restrict tidal exchange between the river and the lake. The purpose of the New Meadows Lake Tidal Restoration Feasibility Study was to develop and evaluate restoration alternatives for improving water quality and enhancing inter-tidal and salt marsh habitat in the Lake. This was achieved by developing and evaluating technical alternatives to increase tidal flow into the Lake at the site of the initial tidal restriction beneath the State Road¹ causeway.

The study began by identifying a range of Conceptual Alternatives that provided general insight into the potential response of the New Meadows Lake system to a variety of conceptual designs. From these, seven Preliminary (Phase 1) Alternatives were subsequently developed in order to evaluate means of enhancing tidal exchange between the fully-tidal reach of the New Meadows River downstream of State Road, and New Meadows Lake upstream of State Road. Lastly, the Final Alternatives analysis focused on the ability of three selected Final Alternatives to achieve the project goals of improved water quality and restoration of intertidal habitat in New Meadows Lake. As part of the study, the New Meadows River Watershed Project and Casco Bay Estuary Partnership hosted two public forums to present the initial study design and subsequent findings to the public, solicit feedback, and incorporate input from stakeholders into the selection of alternatives. A final public forum is scheduled for October 2006 to present findings from the Final Report.

The study produced findings that enhance overall understanding of ecological dynamics in New Meadows Lake and it provides a range of potential alternatives for addressing the impaired Lake conditions. The evaluation of the Phase 1 Alternatives suggests that the project goals may be achieved through the implementation of a variety of alternatives. The Phase 1 Alternatives provide a range of potential benefits associated with the project goals of tidal restoration. These benefits should be considered relative to potential impacts associated with each alternative, such as public perceptions regarding increased tidal range within the New Meadows Lake system and associated regular exposure of intertidal areas.

The evaluation of the Final Alternatives indicates that these alternatives provide a range of benefits associated with the project goals. All of the Final Alternatives would result in substantial restoration of intertidal habitat (29 to 42 acres) in New Meadows Lake. Restoration of intertidal habitat in Upper New Meadows Lake is limited by the geometry and high channel-bottom elevation of the US Route 1 Bridge. Water quality benefits associated with the Final Alternatives were not obtained due to a lack of data necessary to complete this work. Factors associated with the lack of resolution of potential water quality benefits include the coupled relation between water temperatures in the lake and river and suitable boundary conditions (i.e., ambient water temperatures) in New Meadows River seaward from where temperature is influenced by interaction with the lake.

This study was sponsored by the Casco Bay Estuary Partnership (www.cascobayestuary.org) with support from the Gulf of Maine Council (www.gulfofmaine.org), the New Meadows River Watershed Project (www.bowdoin.edu/new_meadows/index.html/), and the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries [www.nmfs.noaa.gov])). Study funding was provided by NOAA Fisheries. Woodlot Alternatives, Inc. (www.woodlotalt.com/) conducted the study and prepared all preliminary and final reports.

¹ Also referred to as “Bath Road”

1.0 INTRODUCTION

The purpose of the New Meadows Lake Tidal Restoration Feasibility Study was to develop and evaluate restoration alternatives to improve water quality and enhance inter-tidal and salt marsh habitat in New Meadows Lake. This report presents information on the development and evaluation of Conceptual, Preliminary (Phase 1), and Final Alternatives. The purpose of the Phase 1 work was to evaluate means to achieve the project goals by increasing tidal flow, or exchange, at the State Road² causeway, while the focus of the final alternatives analysis was to evaluate the potential of the Final Alternatives to achieve the project goals.

1.1 Problem Statement

Historically, the New Meadows River was an unrestricted tidal system with minimal fresh-water inputs. Due to the construction of three road causeways across the river, however, tidal exchange in the upper river is now restricted, creating what is known as New Meadows Lake (Lake). The US Route 1 causeway was constructed across the Lake in the late 1960's, and resulted in bisection of the Lake into 'upper' and lower reaches. Although salinities in the Lake are typically above 25 parts per thousand (ppt) and therefore reflective of a typical estuary system, the Lake has experienced diminished water quality (e.g., hypoxia) and loss of intertidal habitat.

As part of its goal to improve understanding of the ecological dynamics in the watershed, the New Meadows River Watershed Project Steering Committee identified the need to assess the feasibility of increasing tidal exchange in the lake as a high priority action item in the *New Meadows River Watershed Management Plan* (2004). In 2005, Casco Bay Estuary Partnership (CBEP) was awarded a grant from the Gulf of Maine Council on the Marine Environment to implement a tidal restoration feasibility study in conjunction with the New Meadows River Watershed Project, a collaborative effort initiated in 1999 between the municipalities of Bath, Brunswick, Harpswell, Phippsburg, and West Bath, as well as academic, non-profit, state, and federal partners, to protect, improve and maintain the vitality of the ecological and economic resources of the New Meadows River and its watershed.

The purpose of the New Meadows Lake Tidal Restoration Feasibility Study was to develop and evaluate restoration alternatives to improve water quality and enhance inter-tidal and salt marsh habitat in New Meadows Lake. This report presents information on the development and evaluation of both Conceptual and Preliminary (Phase 1) Alternatives. Phase 1 work focused on evaluating means to achieve the project goals by increasing tidal flow, or exchange, at the State Road causeway.

The conceptual alternatives were developed and evaluated to gain initial insights into the response of the New Meadows Lake system to various restoration schemes and to provide an opportunity for input from the Casco Bay Estuary Partnership and the New Meadows River Watershed Project Steering Committee. In general, the evaluation of the Conceptual Alternatives was intended to provide information suitable for the development of Preliminary (Phase 1) Alternatives that may provide quantifiable restoration benefits. The Phase 1 Alternatives were developed based on insights gained through the evaluation of Conceptual Alternatives and are intended to provide information associated with a broad range of possible alternatives and their associated ability to achieve the project goals.

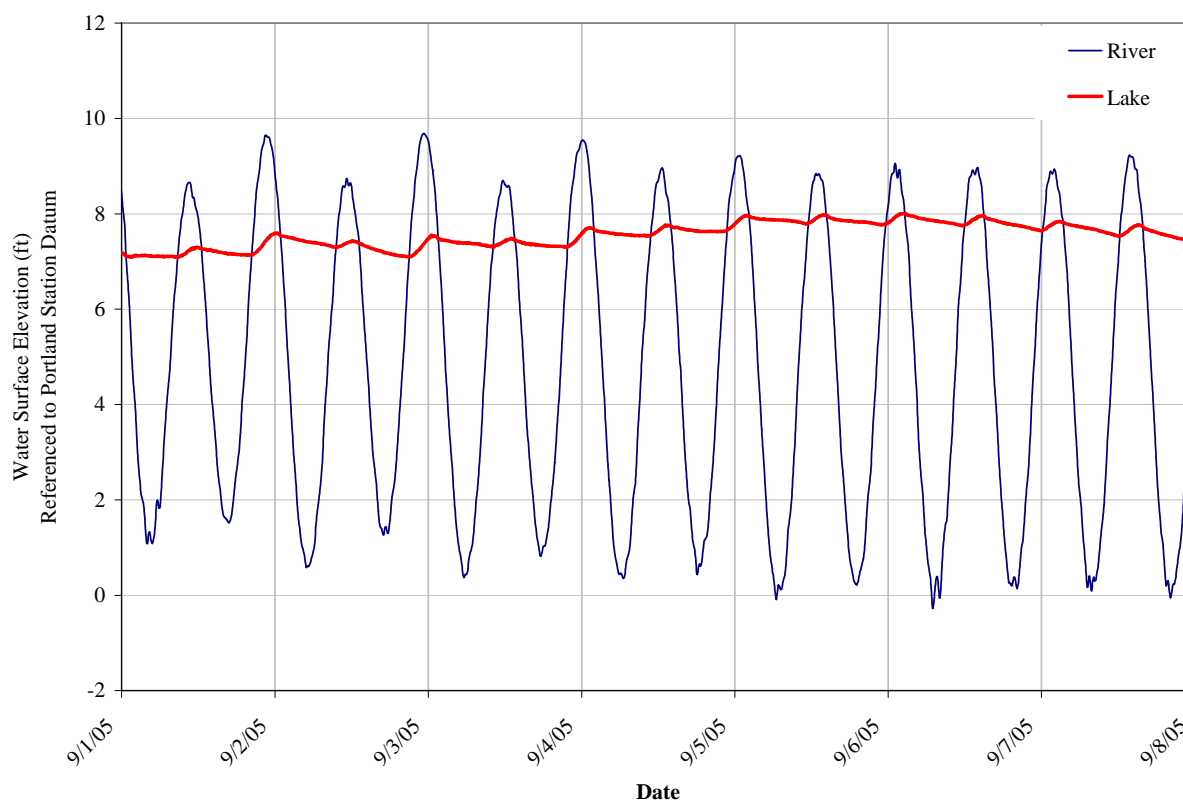
Three Final Alternatives were selected from the Preliminary Alternatives for additional evaluation of project goals associated with restoration of intertidal habitat and improved water quality in New Meadows Lake.

This study was sponsored by the Casco Bay Estuary Partnership (www.cascobayestuary.org) with support from the Gulf of Maine Council (www.gulfofmaine.org), the New Meadows River Watershed Project (www.bowdoin.edu/new_meadows/index.html), and the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries [www.nmfs.noaa.gov]). Study funding was provided by NOAA Fisheries.

1.2 Impairment of New Meadows Lake

New Meadows Lake is a tidal embayment created by the construction of a roadway embankment across the New Meadows River by the Department of the Army in 1937 at State Road, formerly US Route 1. Prior to the construction of this causeway, the hydrology of the New Meadows River experienced semi-diurnal tides and included both inter-tidal and sub-tidal habitats. Due to the restriction imposed by the small opening in the culvert under State Road causeway, the normal tidal range in the Lake is less than one foot. The magnitude of the tidal restriction is evident in Figure 1, which shows tidal stage (i.e., water surface elevations) in New Meadows Lake and the adjacent reach of New Meadows River for the period from September 1–7, 2005. Despite the substantial tidal restriction salinities within the Lake have typically remained above 25 parts per thousand (ppt) due to the Lake's relatively small freshwater watershed.

Figure 1: Tidal Stage in New Meadows Lake and New Meadows Lake



Habitat impairment in New Meadows Lake is indicated by bio-chemical factors such as hypoxia, and physical factors, including the extensive loss of inter-tidal habitat and the presence of *Phragmites australis*, an invasive species, in an 91-acre salt marsh at the head of the Lake north of Old Bath Road. While the Lake currently supports a diverse ecological community, the aforementioned factors indicate substantial impairments to its ecological functions prior to the restriction of tidal flow. Restoration of the

Lake could enhance habitat for a variety of marine species, including shellfish, and enhance opportunities for commercial and recreational harvest.

1.3 Project Study Approach

The goal of this study was to develop and evaluate restoration alternatives at the State Road causeway to improve water quality and enhance inter-tidal and salt marsh habitat in New Meadows Lake. The study was based on a two-phase process, with an initial phase associated with the development and evaluation of Conceptual Alternatives, and the second phase associated with a more detailed evaluation intended to provide for selection of a “feasible” alternative. The study was not intended to address all ecological, engineering, social, and economic issues related to the health and potential restoration of New Meadows Lake. Rather, it was intended to provide critical information that will inform the ultimate decision-making process for the future implementation of a selected feasible alternative. The following objectives were set to implement progress toward the project goal:

Objective 1: Solicit and incorporate stakeholder input.

Objective 2: Review previously collected data and identify additional data needs.

Objective 3: Additional site survey work.

Objective 4: Develop and utilize numerical hydrodynamic models to evaluate alternatives.

Objective 5: Development and evaluation of restoration alternatives.

The study approach included the integration of technical analyses with ongoing participation of the New Meadows River Watershed Project through regular meetings with the New Meadows River Steering Committee and three public forums. The goal of this approach was to provide regular feedback on study progress and findings and to solicit input from interested stakeholders.

The study plan initially included the development of Preliminary and Final Alternatives. This format was modified during the study to provide for review and comment by the New Meadows River Steering Committee of potential Preliminary Alternatives. The study therefore includes three sets of alternatives, which are respectively referred to as Conceptual, Preliminary, and Final Alternatives.

The schedule of the public forums was setup to provide information on the study at its inception, midpoint, and completion. The first public forum was held at the old Brunswick High School on June 27, 2005. The purpose of this forum was to inform the public on the study goals and objectives. The second public forum was held at the West Bath Fire Hall on March 23, 2006. The results of the Preliminary Alternatives evaluation were presented at this forum. The final public forum is scheduled to be held at the old Brunswick High School on October 3, 2006, following the release of the final study report.

2.0 NEW MEADOWS LAKE

New Meadows Lake is a restricted tidal embayment that was formed in 1937 following construction of the US Route 1 causeway connecting Brunswick and Bath, Maine. The goal of this work was improved vehicle access to the shipbuilding industry on the Kennebec River in Bath. The relatively small opening that was constructed through the US Route 1 causeway at the time of its construction created a substantial tidal restriction and resulted in diminished tidal exchange between the lake and the New Meadows River seaward of the causeway. While efforts have been made to increase tidal flushing in the lake through modifications to the existing culvert (including removing stoplogs) these efforts and associated benefits have been limited by the small overall size of the culvert.

The lake was subsequently bisected with the construction of the current US Route 1 causeway across the center of the lake in the late 1960's. The original US Route 1 alignment built in 1937 is now known as State Road. Of note is that the bottoms of the openings under both State Road and US Route 1 are higher than the Mean Tide Level of the New Meadows River seaward of State Road. As a result, normal lake water levels are perched. A third causeway on Old Bath Road represents an additional tidal restriction to a marsh located at the north end of the lake.

Newspaper articles and anecdotal evidence suggest that water quality problems have plagued New Meadows Lake since its creation, and were exacerbated by the bisecting of the lake following the construction of the current US Route 1 alignment. In particular, the location of the new causeway through the approximate center of the lake's longitudinal axis effectively halved the fetch for wind-induced wave setup and potential wave-induced mixing.

For the purposes of this report, the distinction of an 'upper' and 'lower' lake is at times made to distinguish between the water bodies to the north and the south of the current US Route 1 causeway. Use of the term 'lake' by itself refers to both water bodies together as a single system.

2.1 General Hydrology

Daily tidal range in the lake is less than 1 foot due to the tidal restriction at State Road. By comparison, the daily tidal range in the New Meadows River immediately downstream from State Road varies from 8 to 12 feet (ft) during neap and spring tides, respectively.

The surface areas of Lower and Upper New Meadows Lake are 47 and 127 acres, for a total surface area between State Road and Old Bath Road of approximately 174 acres. Approximately 91 acres of marsh situated north of Old Bath Road is hydrologically connected to Upper New Meadows Lake through the bridge on Old Bath Road. The total tributary watershed of the New Meadows Lake system at its point of discharge to the New Meadows River at State Road is 1,009 acres, 265 acres of which are represented by the surface acres of the lake and the marsh north of Old Bath Road.

2.1.1 Tidal Conditions in New Meadows Lake

The typical variation in tidal water surface elevation in New Meadows Lake over a single tidal cycle (12.42 hours) is approximately 0.5 ft, resulting in the exchange of approximately 7 percent of the lake's volume. However, two factors suggest that the effective tidal exchange is somewhat less than this value. The New Meadows River immediately downstream of the State Road Causeway is relatively narrow and restricts mixing of outflows from the lake. This apparently limits mixing of water discharged from the lake with water from the lower New Meadows River and results in recirculation of a previously-discharged "slug" of water. The slug effectively represents a fraction of water that moves between the lake and the river over each tidal cycle that is subject to limited mixing with adjacent waters.

Tidal mixing within the lake may similarly be limited to the lower (southern) section of the lake (Lower New Meadows Lake), as the lower end of Lower New Meadows Lake is similar in width to the adjacent section of the New Meadows River. Analyses performed as part of this study suggest that mixing of inflows from the New Meadows River is limited to the southern reach of Lower New Meadows Lake.



While some mixing of inflows into the balance of the lake is probable, this is likely the result of diffusion³ and not dispersion⁴.

Although variations in salinity can be used to evaluate dispersion in estuarine systems, this approach does not appear to be applicable to the New Meadows Lake system. This is on account of the relatively homogeneous salinity distribution in New Meadows Lake and New Meadows River, which results from the minimal dilution of salt water in the lake due to minimal freshwater inflows.

Freshwater inflows to the lake are limited to relatively small tributaries entering the upper section of the lake (Upper New Meadows Lake). Observations made in the spring of 2006 indicate that flows are less than 1 cubic-foot-per-second from a tributary stream that discharges to the upper section of the lake after passing under the Old Bath Road to the east of the bridge on this road. Although normal freshwater inflows are considered small relative to normal tidal exchange, they may contribute to overall nutrient loading in the lake (on account of agricultural runoff) and bear further investigation.

2.2 Habitat

Aquatic habitat in New Meadows Lake primarily consists of subtidal habitat as a result of the tidal restriction at the State Road causeway. Although there are relatively large expanses of shallow water in Upper New Meadows Lake and along the western side of Lower New Meadows Lake, the perched condition of the State Road culvert precludes exposure of these areas at low tide. Limited intertidal areas occur north of Old Bath Road, but the function of these habitats may be compromised by a lack of tidal flushing and “ponding” of freshwater runoff following precipitation events.

Aquatic habitat in the New Meadows River seaward of the lake is also largely comprised of subtidal habitat areas on account of the morphology of the river, which is characterized by relatively steep shorelines and the relative absence of shallow, intertidal areas. The lack of intertidal areas in the river suggests that the biological integrity of the New Meadows River system was compromised by the loss of relatively large areas of intertidal habitat following the creation of New Meadows Lake.

Terrestrial habitats bounding the lake and river include hardwood-dominated forests. A more diverse assemblage of forest and scrub-shrub swamp borders the less-developed areas adjacent to the 91-acre marsh north of Old Bath Road.

2.3 Water Quality Impairment

Water quality problems in New Meadows Lake have included algae blooms, anoxia and hypoxia, and the formation of “foam” when lake waters discharge to the New Meadows River during ebb tides. A number of previous studies have directly or peripherally considered water quality issues in New Meadows Lake, five of which were reviewed as part of this study and are listed as references to this report. The most relevant of these reports to this study is “*Seasonal Trends Affecting Water Quality in the Lower Lake of the New Meadows River Estuary*” (Schaeffer 2003). This report documents hypoxic (Figures 2C, 3B, 3C) and eutrophic (nutrient rich [Figures 2D, 3B, 3C, 6A, 7A, 8]) conditions in the lake in addition to other relevant information on water quality and associated parameters, including seasonal stratification in Lower New Meadows Lake. Of note is that information presented in this report documents dissolved oxygen (DO) concentrations of less than one milligram per Liter (mg/L) in deeper areas of Lower New Meadows Lake for six of 11 sampling events between April 19, 2002 and April 28, 2003.

³ Diffusion refers to the mixing resulting from random motion and the tendency of a fluid to minimize gradients (e.g., differences in concentration). Vertical turbulent dispersion is considered here to be the most important component associated with vertical mixing in New Meadows Lake.

⁴ Dispersion is the result of velocity differences, or gradients.

The Casco Bay Estuary Partnership (2005) lists the New Meadows River as an area of concern where DO levels may be exacerbated by restricted water circulation. The New Meadows River received a water quality ranking of “poor” according to the Bay’s Health Index Score, which was based on 12 years of monitoring data from 1993-2004 (Battelle 2005). This monitoring report also found that the river had consistently low levels of DO and were reported as approximately 0.5 to 1.0 mg/L lower than the overall mean in summer months⁵. Water temperatures were warmer than the mean in July and August, and cooler than the mean from April to September.

The existing, restricted tidal regime in the New Meadows Lake system has resulted in thermal stratification in portions of the lake and diminished levels of dissolved oxygen. These effects are often linked with declines in the quality of estuarine habitat.

A 1973 report on New Meadows Lake (Wright, Pierce, Barnes, and Wyman) study reported⁶ DO levels between 0 and 10 parts per million (ppm) during summer months. This study also demonstrated correlations between a reduced tidal range and decreased dissolved oxygen.

The State of the New Meadows River (Heinig 2002) suggests that although the estuarine system known as the New Meadows River is healthy and vertically well-mixed overall, certain areas, including the 28-ft “deep hole” in Lower New Meadows Lake are susceptible to abnormal conditions, including hypoxia. The stratified water column profile and high ammonium (NH₄) concentrations in the deep hole may play a role as a significant nitrogen source in the New Meadows River system (Battelle 2005, Shaeffer 2003).

A study of seasonal trends in water quality of Lower New Meadows Lake found the most pronounced stratification in DO concentrations from early spring to late fall, in temperature from June through August, and in salinity in early spring and late fall. Winter sampling data indicate little or no stratification in the water column. This study also highlighted stratified conditions in the deep hole in Lower New Meadows Lake and the link to hypoxic conditions. It further suggests that the unnatural lack of vertical mixing has augmented the effects of stratification on nutrient cycling and biomass productivity.

These reports ultimately suggest that New Meadows Lake is a eutrophic system. The export of excess nutrients from the lake to the adjacent reach of the New Meadows River has the potential to impair water quality in the river. This condition has apparently been documented in late-summer/early-fall when New Meadows Lake “turns over” (i.e., when decreased surface water temperatures result in the loss of thermal stratification). At this point the lake becomes vertically well-mixed, with excess nutrients mixing with the balance of the lake and subsequently discharging to the New Meadows River.

During the course of this study, the New Meadows River Steering Committee received questions about whether excess nutrient loads in New Meadows Lake may result from nutrients discharging from the mouth of the Kennebec River to the southeast of the lake. This suggestion apparently fails on a number of counts. If this suggestion assumes that a constant flow of nutrients enter the lake during flood tides, then the nutrient levels in the lake would also be present in similar concentrations in the tidal waters between the mouth of the Kennebec River and the upper limit of the New Meadows River downstream from the State Road causeway. An alternative assumption, that a “slug” of nutrients discharged from the Kennebec River gets trapped in the lake, ignores the semi-diurnal tidal flushing of the lake and resulting dilution. Regardless of the origin of nutrients in New Meadows Lake, the most apparent cause of degraded water quality is diminished DO levels in the deep hole (hypolimnion) and associated nutrient cycling.

⁵ Note that the NOAA places the hypoxia threshold at 2.0 mg/L. www.cop.noaa.gov/stressors/pollution/current/chrp.html

⁶ All water quality parameters are given in the reported units provided in the referenced reports.

The cause of foam formation in the New Meadows River immediately seaward of the State Road causeway has not been conclusively determined. While the Maine Department of Transportation altered the apron on the seaward side of the State Road causeway in the 1990s as an attempt to alleviate the formation of foam, this problem persists.

Interested parties are encouraged to review the reports referenced here for additional information on water quality in New Meadows Lake and in the New Meadows River.

2.4 Socio-Economic and Land-Use Issues

Socio-economic and land-use issues were not considered in the scope of this study. The solicitation of stakeholder input, as described in Objective 1 in Section 1.3 of this report was intended to provide relevant feedback on these and other, unforeseen issues to provide the Project Partners with information for consideration as part of future studies.

2.5 Project Data

A variety of data sources were used in the development and evaluation of the Conceptual and Phase 1 Alternatives. Existing data sources include plans of bridges and culverts in and adjacent to New Meadows Lake and prior studies of the New Meadows Lake and River. Dedicated survey work was also performed as part of the study. This work included conducting a bathymetric survey of New Meadows Lake and gathering tidal water surface elevation (stage) data in the New Meadows River and Lake downstream and upstream of State Road, respectively.

2.5.1 Project Vertical Datums

The project work was initially referenced to an arbitrary vertical datum (Project Vertical Datum) established during survey work by Woodlot at the existing State Road culvert. The reference point for this datum was an eye-bolt protruding from the west wingwall of the culvert on the north (New Meadows Lake) side of the State Road. An arbitrary elevation of 100 ft was assigned to this point. Tidal stage data and bathymetric data subsequently obtained by Woodlot were referenced to this datum and used to prepare preliminary reports.

The arbitrary vertical datum was subsequently rectified to Mean Lower Low Water (MLLW) = 0.00 at the National Oceanic and Atmospheric Administration (NOAA) tide station in Portland, Maine (Station ID: 8418150) for this work. This was performed by calculating the average water surface elevation from a 6-minute tidal stage data set collected south of State Road in the New Meadows River as part of this study to provide a reference value of Mean Sea Level (MSL). The data set obtained by Woodlot appears reasonable for this purpose given the length of the record (77 days) and the recording equipment was below measured low water during the recording period. This elevation was determined to be 93.86 ft, based on the project vertical datum.

The value of MSL referenced to the project datum was rectified to MLLW using a direct comparison of the calculated MSL value and the reported MSL value for NOAA Station ID 8418150 of 13.49 ft. A correction of -80.37 ft (93.86–13.49) was applied to report data to rectify the project vertical datum to the referenced NOAA tide station. This reference elevation of MLLW for the NOAA station (8.55 ft) was subsequently added to the correction (i.e., $-[80.37+8.55]$) to provide a final correction of -88.92 ft and a tidal reference datum of MLLW = 0.00 ft.

Relevant information for NOAA Station ID 8418150 is presented in Table 1. Additional information is presented in Appendix G.

Table 1: Elevations of Tidal Datums Referenced to MLLW Elevation of = 0.00

Datum	Value (ft)	Description
MHHW	9.91	Mean Higher-High Water
MHW	9.47	Mean High Water
MTL	4.91	Mean Tide Level
MSL	4.94	Mean Sea Level
MLW	0.35	Mean Low Water
MLLW	0.00	Mean Lower-Low Water
GT	1.36	Great Diurnal Range
MN	0.57	Mean Range of Tide

Note that MSL was used in lieu of the Mean Tide Level (MTL) as a reference because the determination of MTL requires the evaluation of minimum and maximum tide elevations for each tidal cycle. This is complicated by the typical appearance of a number of minima and maxima when collecting data over a high period.

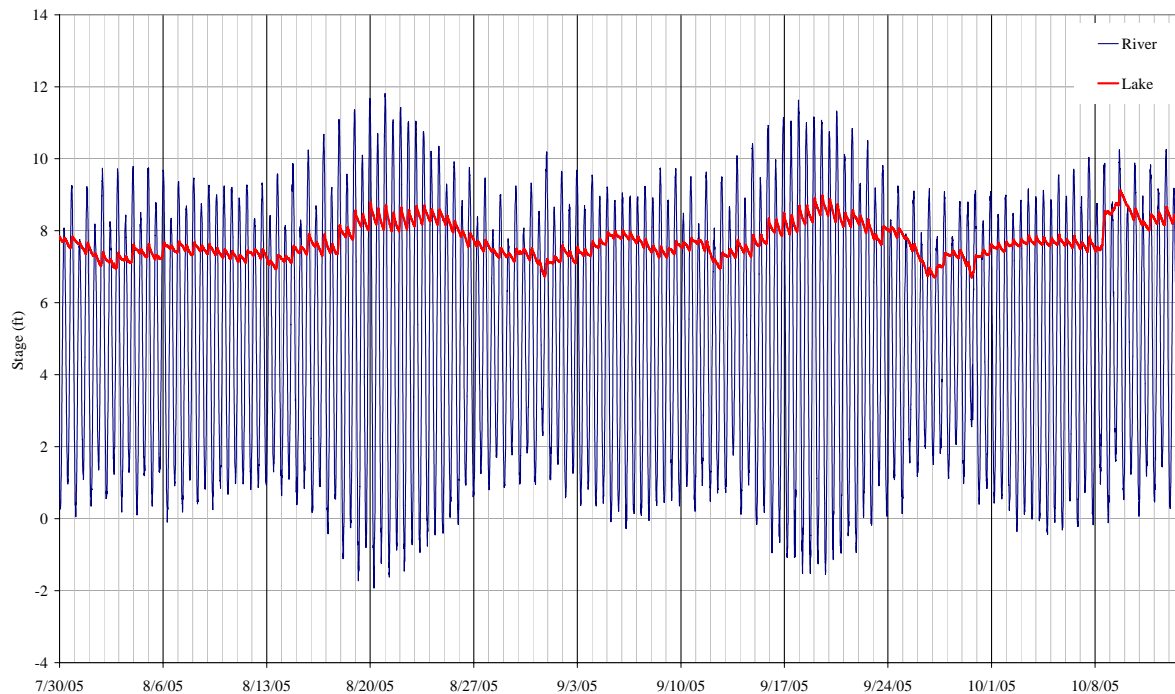
Unless otherwise noted, all references to water surface elevations in this report are to the Portland tide station with MLLW = 0.00 ft.

2.5.2 Tidal Stage Data

Tidal stage data was collected as part of this study on each side of the State Road causeway from July 29 to October 13, 2005. This data was obtained using three HOBO® U20 Water Level Loggers datalogging pressure transducers (pressure transducers) manufactured by Onset Computer Corporation. Unvented pressure transducers were used to minimize the potential for vandalism while deployed. Two pressure transducers were deployed on either side of the State Road causeway in the New Meadows River and Lake, respectively. A third pressure transducer was deployed in the adjacent marina to log variations in barometric (atmospheric) pressure. Information obtained from this pressure transducer was used to correct absolute pressure measurements recorded using the submerged pressure transducers on each side of the State Road causeway.

Pressure data was collected at six-minute intervals during the deployment period. The corrected pressure data was subsequently used to determine the overlying head of seawater at the two submerged pressure transducers. This data was then rectified to the project vertical datum using water surface measurements obtained while the pressure transducers were deployed.

Figure 3 shows the tidal stage data collected as part of this study in Lower New Meadows Lake and in the New Meadows River immediately seaward of the State Road causeway.

Figure 3: Tidal Stage Data for New Meadows River and Lake

2.5.3 Bathymetric Survey

A bathymetric survey of New Meadows Lake was performed using a boat-mounted depth sounder connected to a Trimble™ Pro-XR backpack Global Positioning System (GPS) receiver. The GPS system recorded measured depths, time, and horizontal coordinates along multiple transits within the upper and lower portions of New Meadows Lake. The depth measurements were rectified to the project vertical datum using water surface elevations and corresponding times obtained from the tidal stage data collected in New Meadows Lake immediately upstream from the State Road causeway. This correction assumed that the surface of New Meadows Lake was “flat” during this work, which appears reasonable based on field observations.

Figure 4 shows a bathymetric map of New Meadows Lake developed from the project bathymetric survey, including the approximate limits of typical high and low water levels, as determined from the period during which the Phase 1 Alternatives were evaluated (September 10–25, 2005). Elevations in this figure are referenced to the tidal stage datum described in Section 2.5.1 of this report.

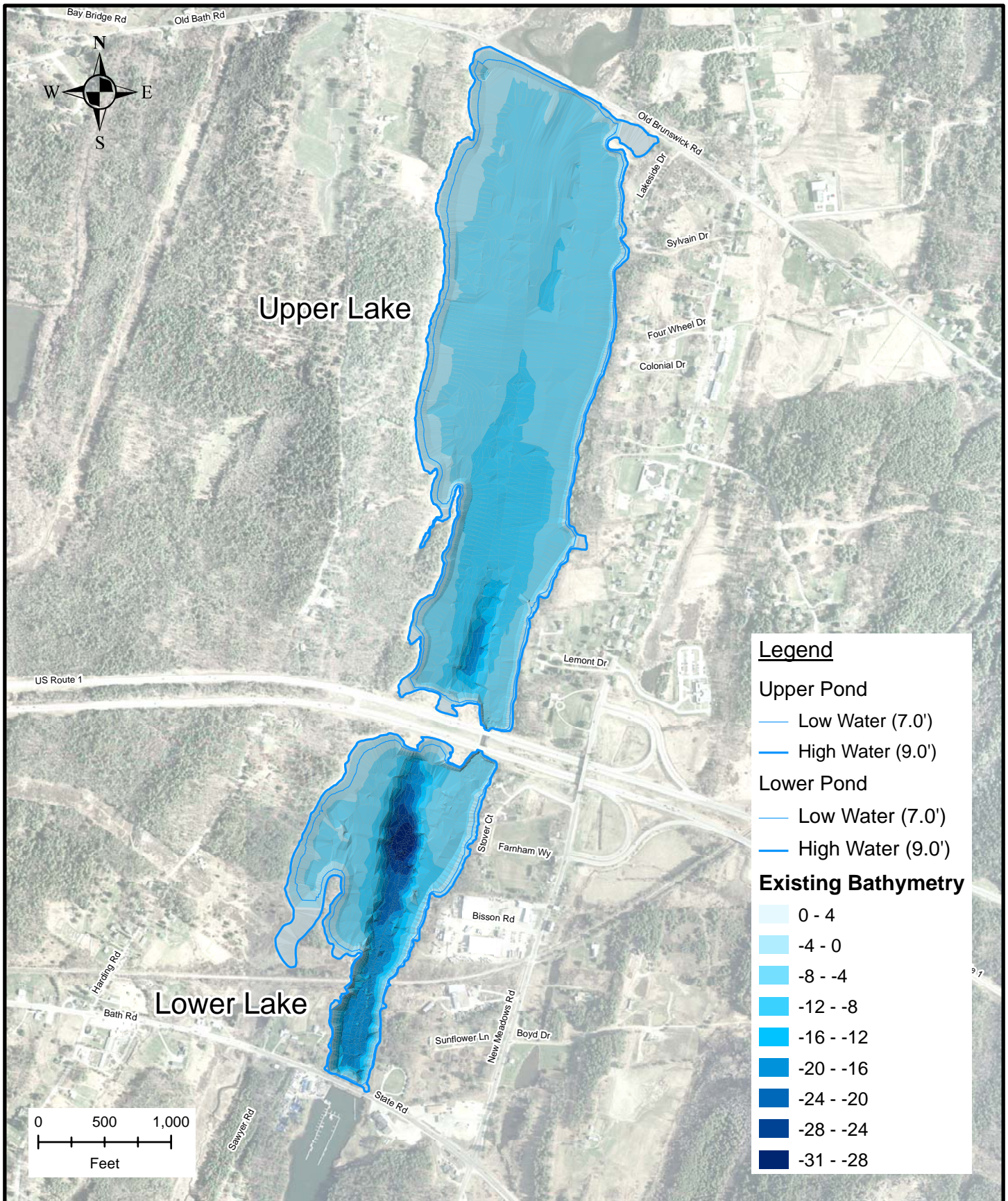
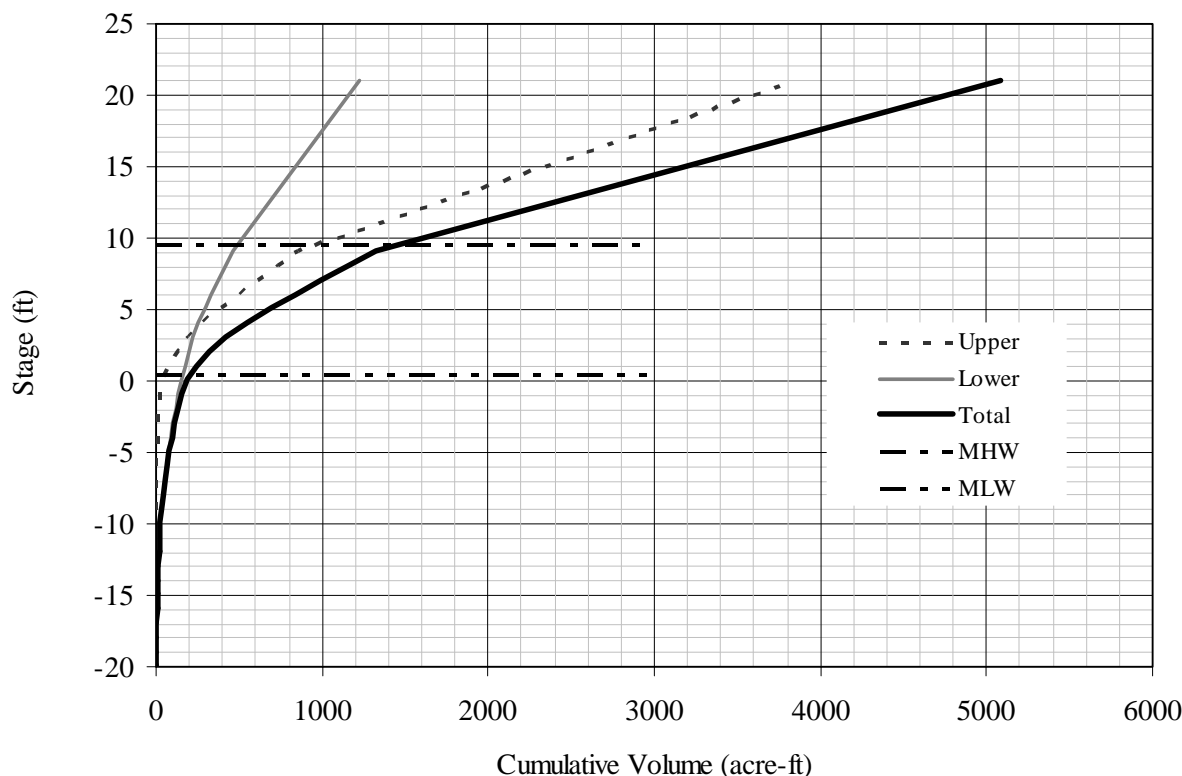


Figure 5 shows stage-volume curves developed from the bathymetric survey work, including curves for the upper (“Upper”) and lower (“Lower”) sections of the lake as well as one for the entire lake (“Total”). A stage-volume curve is a representation of the cumulative volume of a water body over a specified range of elevations. As with the previous figure, elevations in this figure are referenced to the tidal stage datum described in Section 2.5.1 of this report.

Figure 5: Stage-Volume Curves for New Meadows Lake



The stage-storage curves were interpolated above an elevation of 17.6 ft using contour data obtained from the USGS 1:24,000-scale quadrangle map for Bath, Maine. As previously described, a correction factor equivalent to one-half of the map contour interval was added to this elevation. This assumption results in a conservative (i.e., high calculated) water level, as the actual volume of storage will be greater than that determined based on this assumption.

2.5.4 Topographic Data

The bathymetric survey data was augmented using information obtained from the U.S. Geologic Survey (USGS) 1:24,000 scale quadrangle map for Bath, Maine. The shoreline of New Meadows Lake is shown on this map and referenced to Mean High Water. In addition, the 10-ft contour line referenced to the National Geodetic Vertical Datum of 1929 was rectified to the project tidal datum and used to provide an upper limit for the development of stage-storage information for the New Meadows Lake system. The use of the 10-ft contour data included the addition of one-half of the contour interval (5 ft correction for 10-ft contour data) so as to yield higher, and therefore conservative, predicted water levels in the lake at high tide.

As seen in Figure 6, the 10-ft contour line (the first counter line landward of the lake) is generally close to the shore of the lake. With the exception of the southwest corner of Lower New Meadows Lake and the marsh complex north of Old Bath Road, the shorelines along New Meadows Lake are steep and effectively confine much of the lake within the normal wetted area.

3.0 HYDRAULIC MODELING OF ALTERNATIVES

The Conceptual and Phase 1 Alternatives were evaluated using the unsteady flow capabilities of the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) hydraulic model (model). The Conceptual Alternatives were evaluated using a relatively simple model, which was subsequently revised for the evaluation of the Phase 1 Alternatives.

A fundamental approach to the project modeling work was the use of "storage elements" to represent New Meadows Lake. A storage element provides a means to model a body of water where it is desirable to accurately represent changes in storage associated with varying water levels. For this study, each storage element was assigned a stage-volume relation, which essentially describes the storage of the element and therefore the modeled impoundment, at different water levels.

3.1 Conceptual Alternatives Modeling

3.1.1 Conceptual Alternatives Model Geometry

The Conceptual Alternatives were evaluated using a study model consisting of a single storage element representing both the upper and lower areas of New Meadows Lake and associated connecting reaches of the New Meadows River. The stage-storage relation for the single element was developed using bathymetric data obtained as part of the study. The Conceptual Alternatives were evaluated using tidal elevation data collected in the New Meadows River immediately downstream of the State Road Bridge.

3.1.2 Conceptual Alternatives Model Setup

The period of analysis for the conceptual alternative was a six-day period between October 3 and October 8, 2005. To evaluate the ability of the model to predict water surface elevations in New Meadows Lake with a reasonable level of accuracy, the existing culvert was evaluated over the same period. The predicted water levels in New Meadows Lake for the existing conditions were then compared with water level measurements obtained in New Meadows Lake. This comparison suggested that the model performance is reasonable, with differences in calculated and measured water surface elevations typically less than 0.2 ft (2.4-inches).

3.2 Phase 1 Modeling

3.2.1 Phase 1 Model Geometry

The Phase 1 HEC-RAS model geometry is comprised of three channel reaches and two "storage elements" representing the upper and lower sections of New Meadows Lake. The channel reaches include the upper New Meadows River downstream of the State Road causeway, the channel beneath US Route 1 connecting the upper and lower sections of New Meadows Lake, and a "tributary" channel reach connected to the storage element representing Upper New Meadows Lake. The tributary channel reach was used to provide a small base flow (1 cfs) to buffer model stability and to provide a point for modeling of runoff to the lake from upland precipitation.

All modeled scenarios were evaluated using tidal stage data as a boundary, or "forcing" condition, at the downstream limit of this reach. For this study, the boundary condition was used to vary the water surface elevation in the New Meadows River and therefore "force" flow in and out of New Meadows Lake. This boundary condition was established immediately downstream (south) of State Road using tidal stage data collected as part of this study. A set of synthetic channel cross sections were established between State Road and the point of application of the boundary condition. It was assumed that the channel in the upper

river, and therefore the synthetic cross sections, have sufficient hydraulic conveyance capacity to accommodate anticipated flows through all of the evaluated alternatives with minimal head losses.

The model reach representing the channel beneath US Route 1 that connects the upper and lower sections of New Meadows Lake was developed based on survey information obtained as part of this study and information obtained from aerial photography. The limiting factor imposed by this reach is that the bottom of the channel in this reach defines the limit of potential drawdown of the upper section of New Meadows Lake. The approximate limit of this drawdown is an elevation of 11.6 ft.

The tributary reach connected to the storage elevation representing the upper section of New Meadows Lake was used to provide numerical stability in the HEC-RAS model. This reach was assigned a minimal inflow of 1 cubic foot per second (cfs).

Storage elements were selected to model the upper and lower areas of New Meadows Lake. Storage elements were selected in lieu of cross section information due to the low observed flow speeds in the lake and the ability of the storage elements to more accurately model the stage-volume relation in the respective sections of the lake. Stage-volume data for each storage element were developed from bathymetric data collected during this study.

3.2.2 Phase 1 Model Setup

Modeling of existing conditions and Phase 1 Alternatives was performed using tidal stage data collected as part of the project as a downstream boundary condition. Model simulation conditions were selected over ranges of normal and extreme tidal conditions. Model runs within each of the simulation periods were initiated at times where the water surface difference was minimal, as defined by the difference in measured water surface elevations on either side of the State Road causeway. This condition was selected to minimize the possibility of the modeling failing during model warm up.

Tidal stage data were collected as part of this study on each side of the State Road for the period between July 29 and October 13, 2005. The data collected downstream of State Road in the fully-tidal reach of the New Meadows River were used to evaluate existing conditions and Phase 1 Alternatives. Tidal stage data collected upstream of State Road in the lower section of New Meadows Lake were used to calibrate and validate the study model for existing conditions.

3.2.3 Phase 1 Calibration and Validation

The project hydraulic model was calibrated and validated for the existing geometry of the opening under the State Road causeway connecting the New Meadows River to the lower section of New Meadows Lake. Model calibration was performed through the adjustment of model parameters, primarily those associated with the culvert internal boundary condition used in the numerical model.

3.2.3.1 Model Calibration

The model calibration was performed using a 14-day model simulation with tidal data obtained during the period from August 6 to August 20, 2005. Tidal data obtained in the New Meadows River during this period are initially average, with increasing tidal heights towards the end of the period. All model parameters that were adjusted as part of the calibration process are within typical values. The results of the model calibration, including reference data showing the measured water surface elevations in Lower New Meadows Lake and the New Meadows River, are shown in Figure A.1 in Appendix A. As shown in this figure, the calibrated model results for the lower section of New Meadows Lake are consistently close to the measured stage data. Appendix A includes a description key for the water surface elevation (stage) plots referenced above.

3.2.3.2 Model Validation

The purpose of model validation is to compare the ability of the model to predict tidal variations using a data set that varies from that used in the model calibration process. The study model was validated using the calibrated model with a 14-day model simulation and tidal data obtained during the period from September 10 to September 24, 2005. This data set includes a full period of greater high tides differing from that used in the model calibration process.

The results of the model validation, including reference data showing the measured water surface elevations in Lower New Meadows Lake and the New Meadows River, are shown in Figure A.2 in Appendix A. As shown in this figure, the results of the validated model for the lower section of New Meadows Lake are consistently close to the measured stage data.

Figure A.3 in Appendix A shows the results of the model calibration and validation analyses along with the entire set of tidal stage data collected in Lower New Meadows Lake and the New Meadows River as part of this study.

3.3 Phase 2 Modeling

The original goal of the study was to evaluate a subset of the Preliminary Alternatives using a three-dimensional hydrodynamic model. The goal of this was to evaluate whether the Preliminary Alternatives were capable of providing for the propagation of density currents⁷ into the deep hole area of Lower New Meadows Lake. Primary factors that resulted in the decision to not pursue the general use of a three-dimensional model for final analysis include:

- The minimal difference in temperature and salinity of water in New Meadows River and New Meadows Lake, thereby limiting the potential for density current propagation.
- High flow speeds at the culvert and bridge inlets at State Road and US Route 1 for the evaluated alternatives would have required a prohibitively small model time-step.

It was assumed during the scoping phase of the project that there would be substantial difference in water temperature between New Meadows River and New Meadows Lake. Information obtained as part of this study indicates that this temperature difference is minimal. In particular, the temperature data suggests that a “slug” of water that experiences only minimal mixing with water in the lower reaches of the New Meadows River continually flows back and forth through the State Road culvert.

Two-dimensional, depth-averaged hydraulic modeling was not considered suitable for this analysis due to the inherent inability of this model setup to evaluate stratified systems.

⁷ Density currents can form where inflowing water (e.g., inflow from New Meadows River) is of a higher density than ambient or receiving water body (e.g., New Meadows Lake). Increased densities are typically associated with high suspended solids (e.g., salt concentration) and/or lower temperatures in the inflowing water. The ability of a density current to maintain itself without dispersing into the receiving water body is fundamentally related to 1) the speed of the current relative to the ambient water body, and 2) the difference in density between the ambient and receiving waters. This is typically quantified using a ratio known as the “Richardson number.”

4.0 CONCEPTUAL ALTERNATIVES EVALUATION

The Conceptual Alternatives were developed and evaluated to gain initial insights into the response of the New Meadows Lake system to various restoration schemes and to provide an opportunity for input from the Project Partners. In general, the evaluation of the Conceptual Alternatives was intended to provide information suitable for the development of Preliminary (Phase 1) Alternatives that may provide quantifiable restoration benefits with acceptable negative impacts.

Note that the conceptual alternatives were evaluated using the project vertical datum described in Section 2.5.1 of this report.

4.1 Conceptual Alternatives

Following are brief descriptions of the evaluated Conceptual Alternatives, including modeling results and comments addressing each conceptual alternative's relevance in the development of practical preliminary alternatives.

4.1.1 Conceptual Alternative 1: Deeper Culvert

Conceptual Alternative 1 considered the case of a culvert of the same width as the existing box culvert (12 ft) with the invert (bottom) set 2.5 ft below the invert of the existing culvert (94.5 ft). The model analysis of this conceptual alternative indicates that its implementation would result in a lowering of the average water level by approximately 1 foot and a typical tidal range of approximately 1 foot in New Meadows Lake.

In addition to providing marginal restoration benefits, lowering the invert on the existing culvert alignment would likely require removal of bedrock immediately upstream of the existing culvert. Currently, the elevation of bedrock immediately upstream of the culvert in New Meadows Lake is approximately the same or slightly higher than that of the existing culvert invert.

4.1.2 Conceptual Alternative 2: Wider and Deeper Culvert

Conceptual Alternative 2 considered the case of a box culvert with a width of 24 ft, or twice that of the existing culvert, with the invert set 4.5 ft below the invert of the existing culvert. The model analysis of this conceptual alternative indicates that its implementation would result in a lowering of the average water level by approximately 1 foot and a typical tidal range of approximately 2 ft in New Meadows Lake. As with Conceptual Alternative 1, implementation of Conceptual Alternative 2 on the existing culvert alignment would likely be problematic due to the presence of bedrock in New Meadows Lake.

4.1.3 Conceptual Alternative 3: Wider and Deeper Culvert-A

Conceptual Alternative 3 considered the case of a box culvert with a width of 50 ft, with the invert set 7.5 ft below the invert of the existing culvert. The model analysis of this conceptual alternative indicates that its implementation would result in a lowering of the average water level by approximately 2.5 ft and a typical tidal range of approximately 7 ft in New Meadows Lake.

4.1.4 Conceptual Alternative 4: Bridge with Invert Below Mean Low Water

Conceptual Alternative 4 considered the case of a bridge with a width of 50 ft with the channel invert under the bridge set below mean low water in the New Meadows River. The model analysis of this conceptual alternative indicates that its implementation would substantially result in a tidal range in New Meadows Lake similar to that in the New Meadows River downstream of the State Road Bridge.

4.1.5 Conceptual Alternative 5: Wider and Deeper Culvert-B

Conceptual Alternative 5 considered the case of a box culvert with a width of 24 ft with the invert set 7.5 ft below the invert of the existing culvert. The model analysis of this conceptual alternative indicates that its implementation would result in a lowering of the average water level by approximately 2 ft and a typical tidal range of approximately 4 ft in New Meadows Lake.

4.2 Discussion of Conceptual Alternatives

The evaluated Conceptual Alternatives yielded a spectrum of tidal restoration benefits ranging from marginal increases in typical tidal range (Conceptual Alternative 1) through the restoration of unrestricted tidal range (Conceptual Alternative 4) in New Meadows Lake. Figure 7 presents predicted tidal water elevations in New Meadows Lake for the five Conceptual Alternatives and measured water surface elevations in the New Meadows River (downstream boundary condition [DSBC]) and New Meadows Lake. The tidal stage data obtained in the New Meadows River was used as the downstream boundary for the project hydraulic modeling.

While HEC-RAS is not capable of evaluating the lateral alignment of the Conceptual Alternatives along the State Road causeway, Conceptual Alternatives 1 and 2 may be considered evaluations of modifications on the existing culvert alignment, while Conceptual Alternatives 2–5 can be considered evaluations of alternative alignments (e.g., centered on the causeway). Note that Conceptual Alternative 2 may be considered applicable on both the existing and new alignments. The information in Figure 7 was based on an evaluation using tidal data collected for the period from October 3 through October 8, 2005. Note that data and results are only presented for October 7 and 8, 2005, so as not to show anomalous effects associated with model “run-up.”

Figure 7: Tidal Stage Response for Conceptual Alternatives

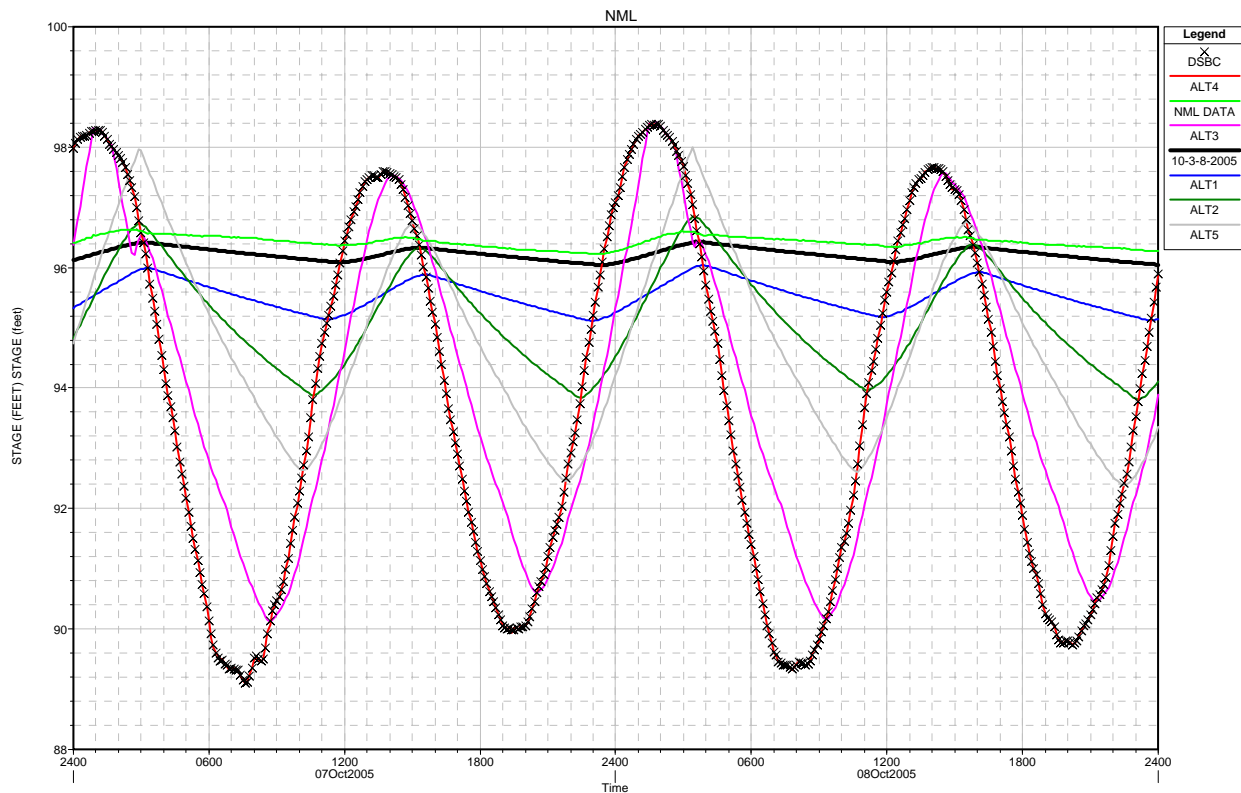


Figure 7 also depicts calculated water surface elevations for the existing culvert (“10-3-8-2005”), which represents the set used for the model analysis. The measured and calculated water surface elevations for the existing conditions are within 0.2 ft, indicating that the selected modeling methodology is acceptable for the evaluation of the Conceptual Alternatives.

Note that the water surface elevations (stage) in Figure 7 are referenced to the project vertical datum described in Section 2.5.1 of this report.

4.3 Other Conceptual Alternatives

The Conceptual Alternatives analysis did not include the evaluation of tide gates or composite alternatives incorporating the existing culvert with new culverts. A typical approach to tidal restoration projects in New England is to install self-regulating tide gates (SRTs). Because of the large size of New Meadows Lake, the large volume of tidal exchange required to achieve meaningful restoration benefits would likely require a large SRT or multiple SRTs. The use of SRTs was not considered following the review of the Conceptual Alternatives.

The evaluation of composite alternatives comprised of the existing culvert with additional culvert openings represents a practical approach, however, the implementation of such an alternative would eliminate the need to remove the existing culvert. A composite alternative was therefore evaluated as one of the Preliminary Alternatives and considered in one of the final alternative sets.

Lowering the invert of the existing culvert was not evaluated as a Conceptual Alternative as this would likely require the complete removal of the existing culvert to allow for substantial excavation, including removal of bedrock under the culvert and bedrock outcropping in Lower New Meadows Lake immediately north of the culvert. In addition, the location of the culvert along the eastern boundary of Lower New Meadows Lake would likely result in relatively quick dissipation of inflowing water speeds as water moves along the edge of the lake, thereby, limiting mixing during flood tides.

Potential interim measures that could be evaluated as Preliminary Alternatives might include means to directly improve water quality in the deep hole. Such an alternative might consist of a siphon system to remove and replace water in the deep hole. This might be accomplished through the installation of a pipe through the causeway of the existing culvert to move water in and out of the deep hole driven by daily variation in tidal stage between New Meadows River and New Meadows Lake.

5.0 PRELIMINARY ALTERNATIVES ANALYSIS

Six Preliminary Alternatives were evaluated in detail using a hydraulic model developed as part of the conceptual alternatives analyses. In addition, two alternative scenarios were evaluated by inspection, or the application of professional judgment. The two alternative scenarios that were evaluated by inspection include 1) the complete removal of the State Road and US Route 1 causeways, and 2) the complete removal of the State Road causeway. In addition, the likely effects of the railroad bridge piers in the lower section of New Meadows Lake are discussed.

The complete removal of the State Road and US Route 1 causeways would result in the unhindered tidal flows in the New Meadows Lake system. Because of the large hydraulic conveyance capacity within the lake, it can be assumed that high tide elevations would increase by approximately 2 ft during typical tide conditions. Similarly, low tides elevations would decrease by 8 to 10 ft. These effects would likely occur well upstream of the Old Bath Road bridge at the upper end of New Meadows Lake.

The complete removal of the State Road causeway would result in the unhindered tidal flows in the lower section of New Meadows Lake and an increase in some change in the tidal range in the upper section of New Meadows Lake and upstream from the Old Bath Road bridge. While high tide elevations in the upper lake would likely increase, low tide elevations would be limited by the bottom of the channel under the US Route 1 causeways. In general, the maximum water surface elevations would likely be similar to those calculated for Preliminary Alternative 6, which evaluates the case of a large bridge at the State Road causeway.

Based on the observed size of the railroad bridge piers situated in the lower section of New Meadows Lake relative to the overall size of the channel, it is unlikely that the piers would have a substantial effect on flows for any of the evaluated scenarios. The potential effect of the piers on hydraulic conveyance was therefore not considered in the evaluation of the Phase 1 Alternatives described below.

Appendix B includes a description key for the water surface elevation (stage) plots referenced below.

5.1 Preliminary Alternatives

Following are brief descriptions of the Preliminary Alternatives, including descriptions of modeling results and comments addressing each alternative's relevance in the development of practical Preliminary Alternatives. For comparison, the recorded tidal range in New Meadows Lake during the Phase 1 period of analysis from September 10 to 24, 2005 was 2.0 ft, and the maximum and minimum water surface elevations were 9.0 and 7.0 ft, respectively.

5.1.1 Preliminary Alternative 1: Deeper Culvert at Existing Location

Preliminary Alternative 1 considered the case of a square (box) culvert of the same width as that of the existing box culvert (12 ft) at State Road with the bottom, or invert, of the culvert set 2.5 ft below the invert of the existing culvert (5.6 ft). The culvert was assumed to have the same overall length as the existing culvert, with wingwalls supporting the adjacent embankment.

The evaluation of this alternative assumed that rock outcrops in the existing channel connecting the culvert to the lower section of New Meadows Lake were lowered slightly. Absent the removal of the bedrock, it is likely that this slightly larger culvert would provide only minimal changes in tidal flow as the bedrock elevation is approximately the same as the lowered culvert bottom.

The analysis of this alternative indicates that its implementation would result in relatively small changes in water surface elevations in the lake and similar water levels in the upper and lower sections of the lake, with range in the lower section of the lake being 0.1 ft greater than that in the upper section of the lake. The calculated tidal range in the lower section of New Meadows Lake for this alternative was 2.5-ft, and maximum and minimum water surface elevations of 8.6 and 6.0 ft, respectively, for the period of analysis.

Figure Alt 1 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.1 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and the lower section of New Meadows Lake during the period of analysis.

5.1.2 Preliminary Alternative 2: Wider and Deeper Culvert at Existing Location

Preliminary Alternative 2 considered the case of a box culvert with a width of 24 ft, or twice that of the existing culvert, with the bottom of the culvert 4.5 ft below that of the existing culvert. The modeling was performed with the assumption that the bedrock outcroppings adjacent to the existing culvert in the lower section of New Meadows Lake would be removed to provide additional flow capacity. The culvert was assumed to have the same overall length as the existing culvert, with wingwalls supporting the adjacent embankment.

The analysis of this alternative indicates that its implementation would result in substantial changes in water surface elevations in the lake. These calculated water levels in the lower section of the lake result in a tidal range of 7.0 ft, and maximum and minimum water surface elevations of 10.5 and 3.5 ft, respectively, for the period of analysis. These calculated water levels in the upper section of the lake result in a tidal range of 3.2 ft, and maximum and minimum water surface elevations of 9.0 and 5.8 ft, respectively, for the period of analysis.

Figure Alt 2 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.2 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and lower section of New Meadows Lake during the period of analysis.

As with Preliminary Alternative 1, implementation of Preliminary Alternative 2 on the existing culvert alignment would require the removal of bedrock adjacent to the culvert in the lower section of New Meadows Lake.

5.1.3 Preliminary Alternative 3: Two Larger Culverts at New Location

Preliminary Alternative 3 considered the case of a pair of box culverts, each with widths of 24 ft with their bottoms set 7.5-ft below the invert of the existing culvert. This alternative would be appropriate for installation at a new location along the State Road causeway and would require a substantially longer culvert. For this analysis, a culvert length of 80 ft was assumed.

The analysis of this alternative indicates that its implementation would result in substantial changes in water surface elevations in the lake. These calculated water levels in the lower section of the lake result in a tidal range of 11.3 ft, and maximum and minimum water surface elevations of 11.5 and 0.2 ft, respectively, for the period of analysis. These calculated water levels in the upper section of the lake result in a tidal range of 3.2 ft, and maximum and minimum water surface elevations of 9.5 and 6.3 ft, respectively, for the period of analysis.

Figure Alt 3 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.3 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and lower section of New Meadows Lake during the period of analysis.

Implementation of this alternative would require a new culvert alignment through the State Road causeway.

5.1.4 Preliminary Alternative 4: Single Larger Culvert at New Location

Preliminary Alternative 4 considered the case of a single box culvert with a width of 24 ft and its bottom set 7.5 ft below the invert of the existing culvert. As with Preliminary Alternative 3, this alternative would be appropriate for installation at a new location along the State Road causeway and would require a substantially longer culvert. For this analysis, a culvert length of 80 ft was assumed.

The analysis of this alternative indicates that its implementation would result in substantial changes in water surface elevations in the lake. These calculated water levels in the lower section of the lake result in a tidal range of 10.0 ft, and maximum and minimum water surface elevations of 11.0 and 1.0 ft, respectively, for the period of analysis. These calculated water levels in the upper section of the lake result in a tidal range of 3.1 ft, and maximum and minimum water surface elevations of 9.3 and 6.2 ft, respectively, for the period of analysis.

Figure Alt 4 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.4 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and lower section of New Meadows Lake during the period of analysis.

Implementation of this alternative would require a new culvert alignment through the State Road causeway.

5.1.5 Preliminary Alternative 5: Composite of Existing and New Culverts

Preliminary Alternative 5 considered the case of the culvert modeled in Preliminary Alternative 4 without the removal of the existing culvert.

The analysis of this alternative indicates that its implementation would result in substantial changes in water surface elevations in the lake. These calculated water levels in the lower section of the lake result in a tidal range of 10.1 ft, and maximum and minimum water surface elevations of 11.1 and 1.0 ft, respectively, for the period of analysis. These calculated water levels in the upper section of the lake result in a tidal range of 3.1 ft, and maximum and minimum water surface elevations of 9.4 and 6.2 ft, respectively, for the period of analysis. These values are similar to those determined for Preliminary Alternative 4. The small decrease in tidal range associated with this alternative apparently resulted from rounding off the calculated water surface elevations. Regardless, the evaluation of this alternative suggests that benefits associated with Preliminary Alternatives 4 and 5 are approximately equivalent.

Figure Alt 5 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.5 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and lower section of New Meadows Lake during the period of analysis.

Implementation of this alternative would require a new culvert alignment through the State Road causeway.

5.1.6 Preliminary Alternative 6: Bridge with Invert Below Mean Low Water

Preliminary Alternative 6 considered the case of a bridge with a bottom width of 30 ft set below low water in the New Meadows River. The bridge opening was modeled with a length of channel of 70 ft and side slopes set at a slope of 1.5:1 (horizontal:vertical).

The analysis of this alternative indicates that its implementation would result in substantial changes in water surface elevations in the lake. These calculated water levels in the lower section of the lake result in a tidal range of 12.0 ft, and maximum and minimum water surface elevations of 11.6 and -0.4 ft, respectively, for the period of analysis. These calculated water levels in the upper section of the lake result in a tidal range of 3.3 ft, and maximum and minimum water surface elevations of 9.6 and 6.3 ft, respectively, for the period of analysis. These values are similar to those determined for Preliminary Alternative.

Figure Alt 6 in Appendix C depicts calculated high and low water levels in the upper and lower sections of New Meadows for this alternative. Figure B.6 in Appendix B depicts calculated stage data for the upper and lower sections of New Meadows Lake for this alternative during the period of analysis. This figure also shows tidal stage data obtained from the New Meadows River and lower section of New Meadows Lake during the period of analysis.

Implementation of this alternative would require a bridge alignment through the State Road causeway.

5.1.7 Evaluation of Upland Runoff

The development of the preliminary alternatives model included provisions for the evaluation of upland runoff on water levels in New Meadows Lake using the simulated tributary reach entering Upper New Meadows Lake.

The extreme rainfall event that began on October 8, 2005 was conceptually simulated using the Preliminary Alternatives model by routing a simulated runoff hydrograph into Upper New Meadows Lake. This conceptual analysis was performed using a simulated hydrograph equivalent to 10 inches of runoff over the New Meadows Lake watershed, including the lake. The simulated hydrograph include a rising limb from one to 211 cfs over a period of 24 hours (211 cfs is the value of uniform hydrograph over a period of 24 hours (hrs) for the New Meadows Lake watershed and lake), uniform runoff of 211 cfs for 12 hrs, and a falling limb from 211 cfs to 1 cfs over 48 hrs, for a total hydrograph period of 84 hrs.

Figure E.1 in Appendix E shows the results of this simulation along with water surface elevation measurements obtained as part of this study in Lower New Meadows Lake and the New Meadows River. As shown in this figure, the results of this conceptual simulation are in general agreement with the measured water surface elevation in Lower New Meadows Lake. A detailed analysis of this hydrologic event was beyond the scope of this study.

6.0 RESULTS FROM PRELIMINARY ALTERNATIVES ANALYSIS

The results of the preliminary alternatives analysis indicate that a variety of approaches may provide benefits associated with the project goals. Because the preliminary modeling approach assumed no changes to the existing US Route 1 bridge geometry between the upper and lower sections of New Meadows Lake, potential benefits associated with increased tidal variation are limited in the upper section of the lake due to the relatively high channel under the bridge.

Water surface elevations and associated water surface elevation, or stage, plots calculated as part of the preliminary alternatives analysis are presented in Table 1 and in Appendix B. Plan maps showing the limits of high and low water in the upper and lower sections of New Meadows Lake for the preliminary alternatives are presented in Appendix C.

Table 2: Preliminary Alternatives Analysis Results

Final Alternative Scenario No.	Preliminary Alternative Scenario No.	Maximum High and Minimum Low Tides during Analysis Period (ft)				Calculated Stage (ft)				Magnitude of Tidal Restriction (ft)				Change in Stage (ft)				Tidal Range (ft)		
		NMR		L NML		L NML		U NML		L NML		U NML		L NML		U NML		L NML	U NML	Tidal Range in U NML vs.L NML
		High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low			
-	Data	11.7	-1.6	9.0	7.0	-	-	-	-	2.7	8.5	2.7	8.5					2.0	2.0	
-	Model	11.6	-1.6	9.0	7.0	8.7	7.1	8.7	7.1	2.9	8.6	2.9	8.6	-0.3	0.1	-0.3	0.1	1.7	1.7	100%
-	Alt 1	11.6	-1.6	9.0	7.0	8.5	6.0	8.5	6.1	3.1	7.6	3.2	7.6	-0.5	-0.9	-0.5	-0.9	2.5	2.4	96%
1	Alt 2	11.6	-1.6	9.0	7.0	10.5	3.5	9.0	5.8	1.2	5.1	2.7	7.4	1.5	-3.5	0.0	-1.1	7.0	3.2	45%
3	Alt 3	11.6	-1.6	9.0	7.0	11.5	0.2	9.5	6.3	0.1	1.7	2.1	7.8	2.5	-6.8	0.5	-0.7	11.3	3.3	29%
2	Alt 4	11.6	-1.6	9.0	7.0	11.0	1.0	9.3	6.2	0.7	2.6	2.3	7.8	2.0	-5.9	0.3	-0.7	10.0	3.1	31%
2	Alt 5	11.6	-1.6	9.0	7.0	11.1	1.0	9.4	6.2	0.6	2.6	2.3	7.8	2.1	-5.9	0.4	-0.7	10.1	3.1	31%
3	Alt 6	11.6	-1.6	9.0	7.0	11.6	-0.4	9.6	6.3	0.0	1.1	2.1	7.8	2.7	-7.4	0.6	-0.7	12.0	3.3	27%

Note: *Bold Values Represent Measured Values*
 “NMR” – “New Meadows River”
 “L NML” – “Lower New Meadows Lake”
 “U NML” – “Upper New Meadows Lake”

7.0 FINAL ALTERNATIVES ANALYSIS

The three Final Alternatives are comprised of Preliminary Alternatives 2 through 6. The Final Alternatives provide a broad range of potential restoration options from a larger culvert at the current location (Preliminary Alternative 2) to the construction of a bridge (Preliminary Alternative 6). For continuity, the Final Alternatives will be referenced based on the numbering scheme implemented during the Preliminary Alternatives evaluation.

Two of the Final Alternatives are comprised of a pair of Preliminary Alternatives, as noted above. The decision to combine the alternatives was made based on their similar characteristics as determined during the preliminary alternatives analysis. The Final Alternatives are:

- Final Alternative 1 (Preliminary Alternative 2)
- Final Alternative 2 (Preliminary Alternatives 4 and 5)
- Final Alternative 3 (Preliminary Alternatives 3 and 6)

The ordering listed above represents the increasing magnitude of restoration benefits associated with each of the Final Alternatives. Note that the Final Alternatives do not evaluate potential modifications to the tidal restriction imposed by the US Route 1 causeway and bridge and associated affects on tidal exchange in New Meadows Lake.

The Final Alternatives do not consider changes to the geometry of the US Route 1 Bridge or the underlying channel. This bridge is currently not a tidal restriction on account of the small tidal range in New Meadows Lake, but the results of the preliminary alternatives evaluation indicate that it would limit the tidal range in Upper New Meadows Lake to between 27 and 45 percent of that in Lower New Meadows Lake based on the three Final Alternatives. This effect largely results from the relatively high channel bottom elevation under the existing bridge. The implementation of the Final Alternatives would substantially increase flow speeds under the bridge, and would require the implementation of new scour countermeasures. Note that the probable opinions of cost for final design and implementation presented in Section 8.4 include costs for work associated with the design, permitting, and implementation of revised scour countermeasures at the US Route 1 Bridge.

Preliminary Alternative 1 was not selected as a final alternative based on the results of the preliminary alternatives analysis (Section 5.1.1). Implementation of this alternative would provide marginal restoration benefits.

7.1 Final Alternatives Analysis Methodology

The purpose of the final alternatives analysis was to evaluate means to improve water quality and restore intertidal habitat in New Meadows Lake. Recognizing the potential for socio-economic constraints associated with gross increases in tidal range in New Meadows Lake, the initial intent of this study was to evaluate the potential for limiting thermal stratification in the deepest areas of the upper and lower lake.

An initial assumption was that this could be achieved through relatively small increases in tidal range and exchange through the introduction of colder water from the New Meadows River seaward of the State Road causeway and the propagation of density currents of well-oxygenated water into the deep hole. A particular benefit of this approach is that the introduction of higher-quality water into stratified areas of the lake does not need to destabilize stratified areas over a single tidal cycle; it must only prevent the formation of hypoxic conditions. Persistent levels of acceptable dissolved oxygen in these areas would

effectively result in the restoration of subtidal habitat and reduce nutrient cycling that accompanies hypoxia.

7.1.1 Temperature Gradient

The assumption of density current propagation was predicated on the assumption of substantial differences in temperature between the waters of New Meadows Lake and the adjacent reach of the New Meadows River. Temperature data obtained with the tidal stage data collected as part of this study on each side of the State Road causeway from July 29 to October 13, 2005, was used to determine variations in between the lake and the river. Temperature data obtained in New Meadows Lake and tidal stage data obtained in the New Meadows River adjacent to the State Road causeway are shown in Figure 8. The regular (twice-daily) variations in temperature in this figure are associated with ebb and flood tides.

Figure 8: Temperature in New Meadows Lake/Tidal Stage in New Meadows River

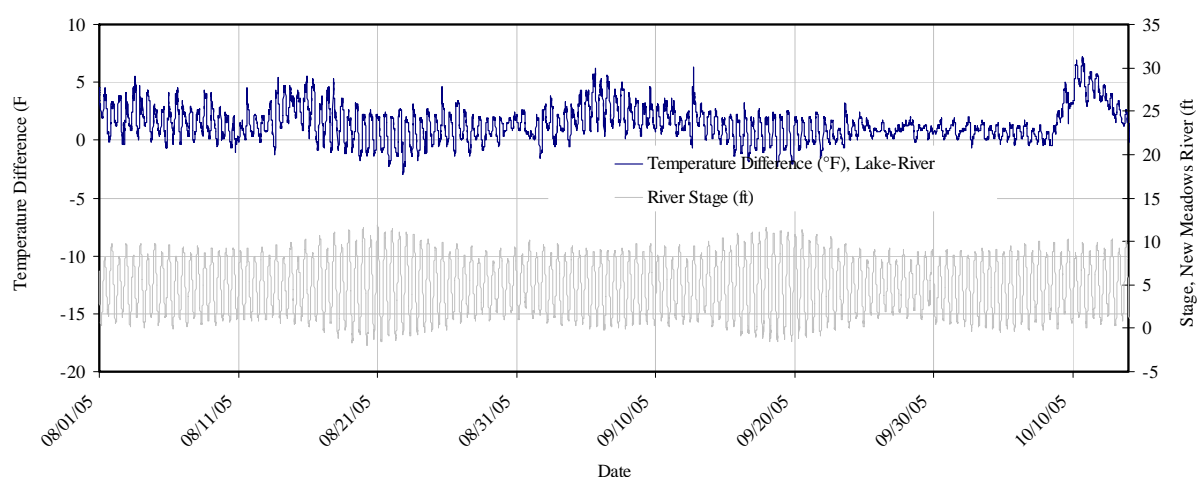
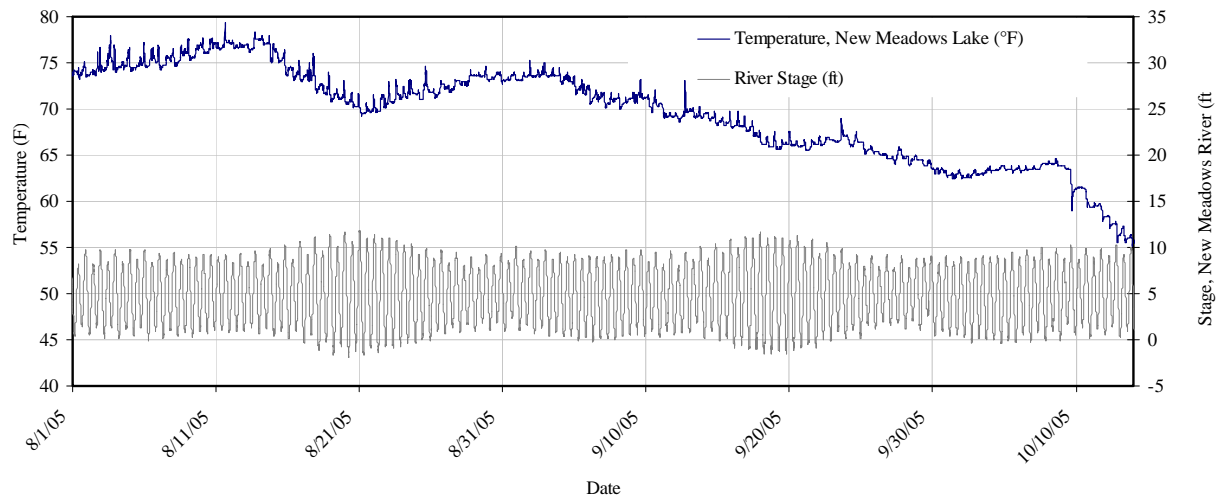


Figure 9 shows the difference in water temperatures between New Meadows Lake and New Meadows River and the tidal stage in the New Meadows River. While the data set is limited to the end of summer, and includes only one full (28-day) tidal cycle during this period, there is apparently a relation between differences in water temperature and neap and spring tides.

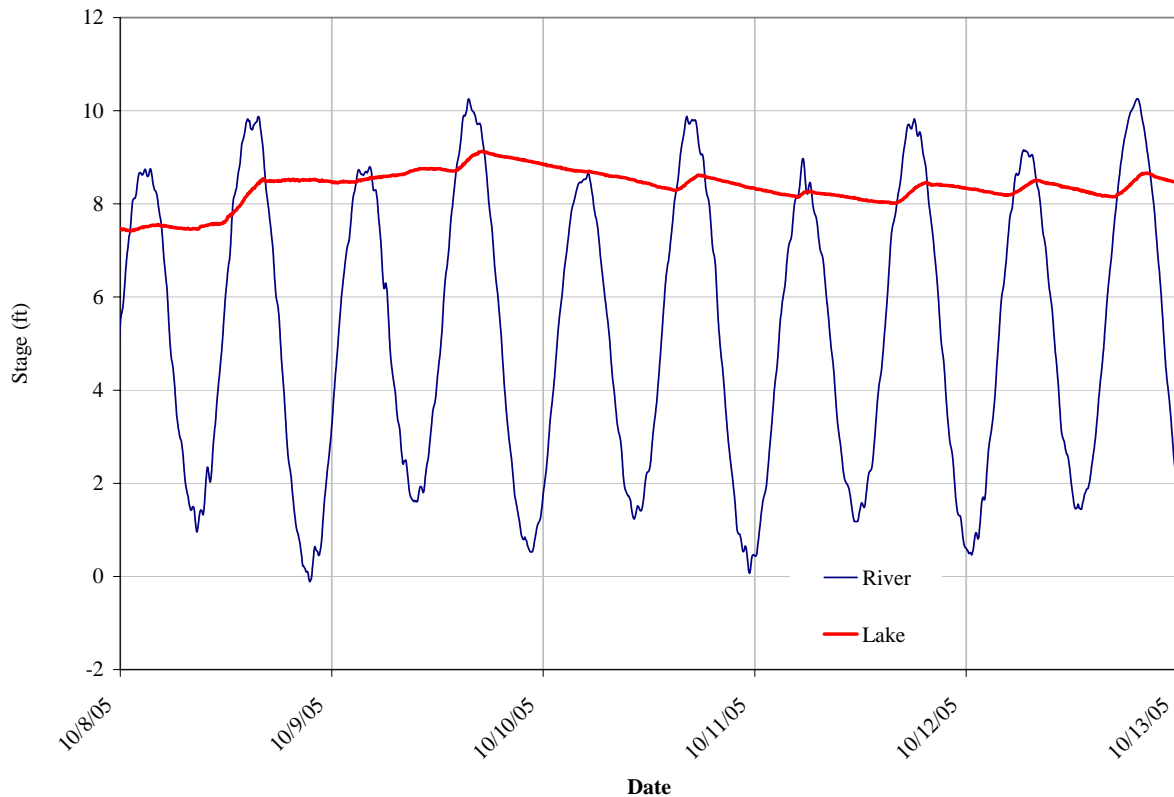
As shown in Figure 9, the difference in waters temperatures between New Meadows Lake and New Meadows River reached a maximum of approximately 5 degrees Fahrenheit towards the end of the two neap tidal cycles between August 1 and September 20, 2005. This difference diminishes with the onset of the spring tidal cycles.

Figures 2A and 3A in Schaeffer (2003) suggest that fall turnover of Lower New Meadows apparently occurred in late-September and/or early October of 2002. This seasonal period would coincide with the period of minimal temperature differences shown in Figure 9. The period of increased temperature differences in Figure 9 beginning on October 8, 2005 coincides with the extreme precipitation event that occurred from October 8-10, 2005, and is mirrored by the prolonged high water surface elevations in Lower New Meadows Lake during that period, as shown in Figure 10 of this report. A more thorough evaluation of this occurrence would need to evaluate precipitation and ambient water temperatures and mixing in the New Meadows River.

Figure 9: Temperature Difference Between New Meadow Lake and River / Tidal Stage in New Meadows River



Note that the spike in temperature difference beginning on October 8, 2005, coincided with a major, two-day rainfall event (Figure 10). During the first high tide on October 10, 2005, water levels in New Meadows Lake remained above those in the New Meadows River, resulting in water discharging from the lake over two tidal cycles. Observations by others from the State Road causeway confirm that tidal reversal into New Meadows Lake did not occur during this period. A discussion of a conceptual simulation of this event was presented in Section 5.1.7 of this report. Figure E.1 in Appendix E shows the results of this simulation.

Figure 10: Tidal Stage, October 8 – 13, 2005

The aforementioned relation is likely related to factors including, decreased mixing of water between the lake and the river during neap tidal cycles. This apparent lack of mixing may also occur within the adjacent areas of the lake and river, and that a relatively poorly-mixed “slug” of water tends to move between the lake and the river. Similarly, the onset of the spring tidal cycle increases both the exchange of water between the lake and river and mixing of water within adjacent sections of the New Meadows River. This indicates that water temperatures in the lake and river are functionally related to the volume of tidal exchange and mixing of waters within the lake and the river.

Lacking additional information on water temperatures and mixing in the New Meadows River below the study area, changes in water temperatures resulting from increased tidal exchange in New Meadows Lake were not evaluated. Temperature differences between water in the lower section of Lower new Meadows Lake were assumed to be insufficient for the propagation of density currents into the deep hole in Lower New Meadows Lake, and the evaluation of entrainment was evaluated assuming no difference in water temperature, and therefore density, between the lake and the river.

7.1.2 Jet Propagation

Mixing of tidal flow into New Meadows Lake was assumed to be similar to that of a “jet” of water entering a static, ambient environment. The purpose of this evaluation was to determine the extent of jet propagation in Lower New Meadows Lake, with an emphasis on whether the jets persist for sufficient distances to upset stratification in the deep hole, approximately 1600 ft north of the State Road causeway.

Idealized jet parameters were developed for each of the three Final Alternatives (Table 3). These idealized parameters were then used to evaluate mixing of tidal inflows with no difference in fluid properties between the jet and ambient fluids.

Table 3: Idealized Jet Parameters

Final Scenario No.	Preliminary Alternatives	Jet Speed (fps)	Jet Flow (cfs)	Jet Cross Section (ft ²)	Distance from Bottom of Jet to Lake Bottom (ft)	Ambient Depth (ft)
1	2	15	1100	72	10	16
2	4,5	5	1350	260	5	16
3	3,6	3	1800	550	5	16

The evaluation of the maximum time-averaged speed along the centerline of the idealized jet for each of the Final Alternatives indicates that the jet-speeds dissipate rapidly moving away from the point of discharge, as shown in Figure 11.

Figure 11: Maximum Time-Averaged Speed (Centerline)

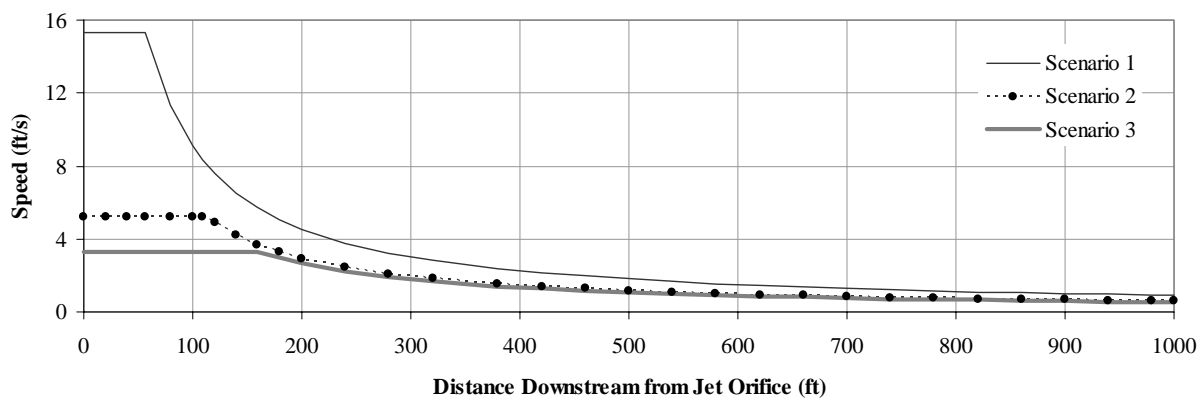


Figure 11 depicts the idealized jet widths at 0.5 foot-per-second (ft/s). In this figure it is seen that the higher flow speeds associated with Final Alternative 1 result in a jet that propagates further into the lake.

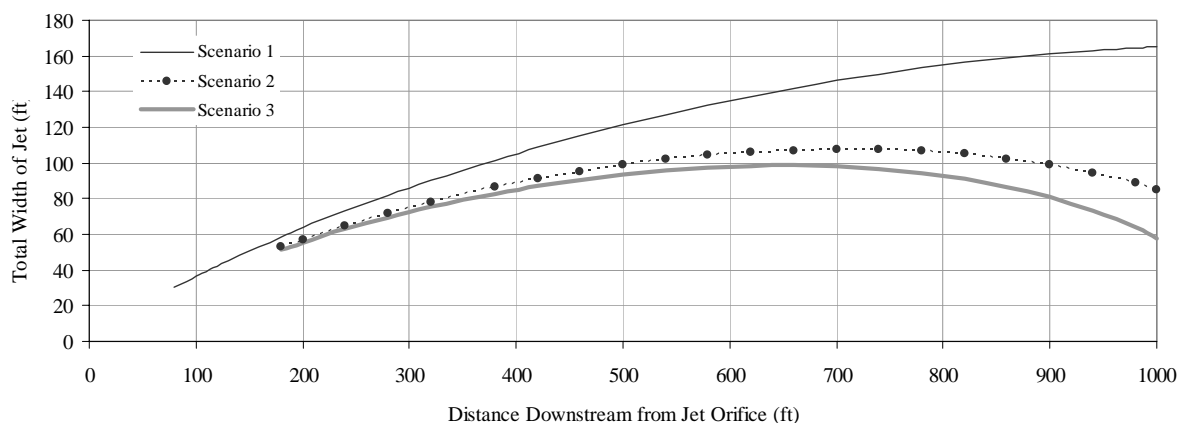
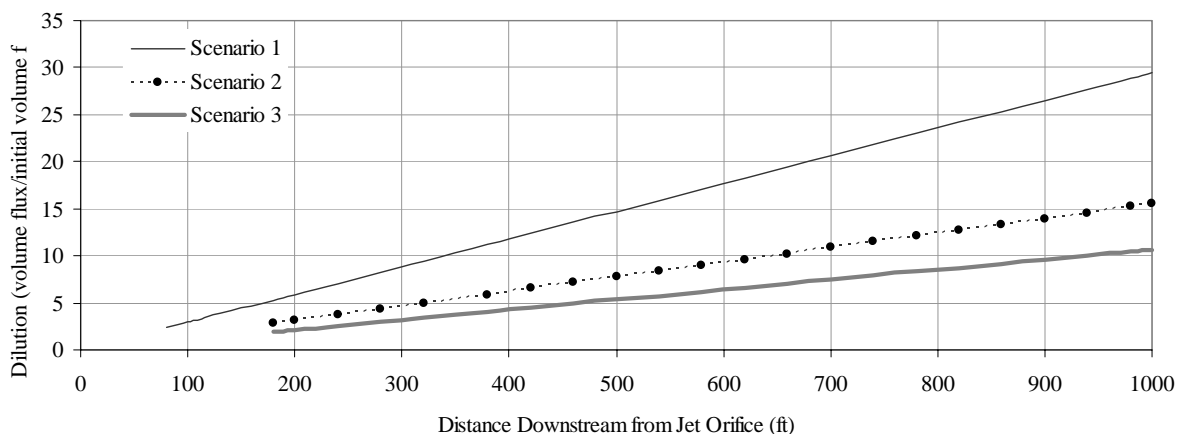
Figure 12: Jet Width at 0.5 ft/s Contour

Figure 13 depicts the dilution, or entrainment of ambient water, associated with the final alternative jets. At 1000 ft, each of the jets has been diluted with ambient water by a minimum factor of 10. A consequence of this dilution is that differences in fluid properties, including temperature, are diminished. For example, an initial temperature difference of 10 degrees Fahrenheit would be reduced to approximately 1 degree barring the formation of a density current.

Figure 13: Jet Dilution

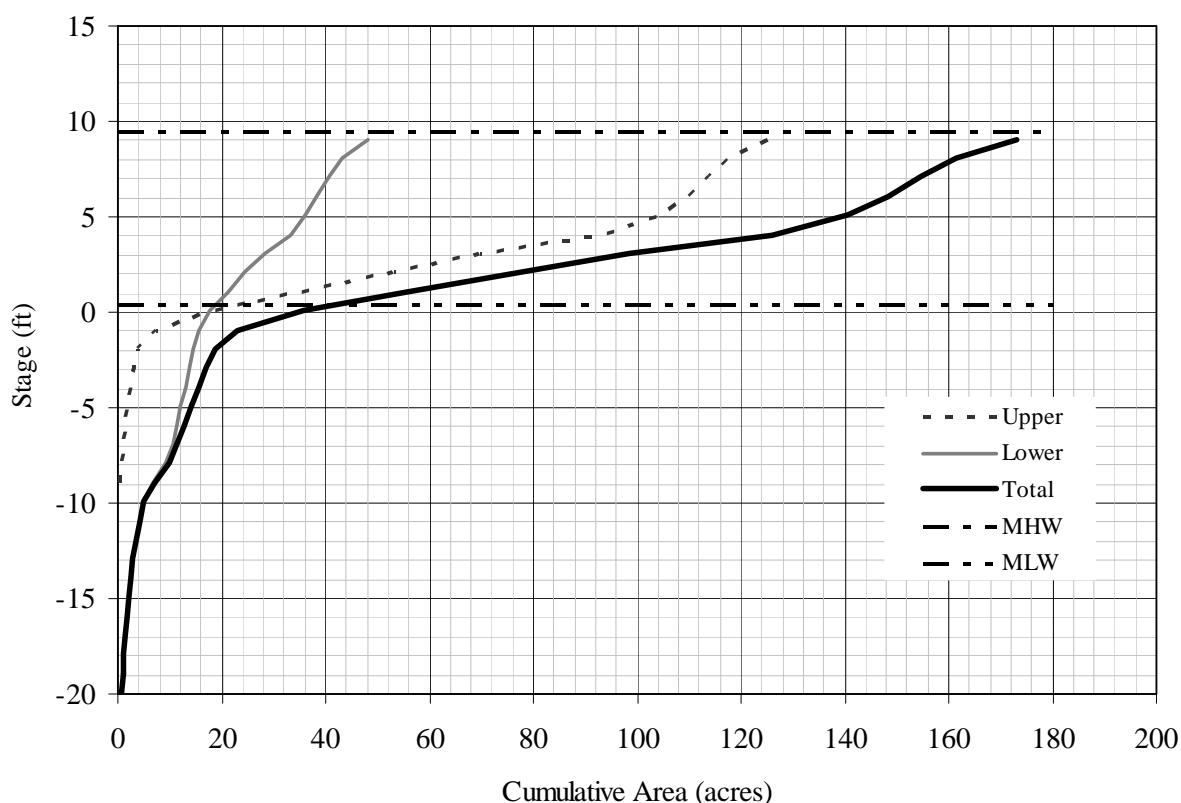
This evaluation of jet propagation for the Final Alternatives suggests that jets propagating from openings in the State Road causeway will have a marginal effect on flow speeds in the vicinity of the deep hole in Lower New Meadows Lake. An additional step taken as part of this evaluation was performed using an idealized three-dimensional hydraulic analysis of jet propagation in Lower New Meadows Lake. This analysis is presented in Appendix F of this report. The results of this additional evaluation tend to confirm the jet propagation analysis presented above, and indicate that flows originating at the State Road causeway have a marginal affect on conditions in the vicinity of the deep hole.

7.1.3 Restoration of Intertidal Habitat

Intertidal habitat in New Meadows Lake is currently limited to small areas along the margins of the lake and small areas within the approximately 91-acre marsh north of Old Bath Road. Areas of restored intertidal habitat associated with each of the Final Alternatives were evaluated using water surface

elevations determined as part of the preliminary alternatives evaluation and hypsometric data for the lake. While areas of restored intertidal habitat in Lower New Meadows Lake are largely correlated with increased tidal range associated with each of the Final Alternatives, the hydrogeometry of the lower lake limits these benefits. Figure 14 presents hypsometric curves (area vs. stage) for Upper and Lower New Meadows Lake and for the entire lake between State Road and Old Bath Road, excluding USGS topographic data. Of note in this figure is the large area of potential intertidal habitat in Upper New Meadows Lake. By reference, the elevations of Mean Low Water and Mean High Water are approximately 0.35 ft and 9.37 ft, respectively, based on information for the referenced NOAA tide station.

Figure 14: Hypsometric Curves



Areas of restored intertidal habitat for the Final Alternatives are presented in Table 4. The restored areas of intertidal habitat represent a substantial overall increase in intertidal habitat in the New Meadows River system due to the dominance of steep rock along the edge of the river and the general lack of intertidal habitat in the upper reach of the river seaward of State Road.

Table 4: Restored Intertidal Habitat

Final Alternative No.	Lower New Meadows Lake			Upper New Meadows Lake			Total
	High Water Elev. (ft)	Low Water Elev. (ft)	Intertidal Habitat (acres)	High Water Elev. (ft)	Low Water Elev. (ft)	Intertidal Habitat (acres)	Intertidal Habitat (acres)
1	10.5	3.6	15	9.0	5.9	14	29
2*	11.0	1.1	25	9.4	6.3	12	37
3**	11.7	-0.5	30	9.6	6.3	12	42

Note: * Values based on evaluation of Preliminary Alternative 4.

**Values based on evaluation of Preliminary Alternative 6.

As previously discussed, the relatively high channel bottom elevation under the existing US Route 1 Bridge limits the tidal range in Upper New Meadows Lake and therefore limits the potential to restore intertidal habitat. Barring this restriction, areas of restored intertidal habitat would greatly increase in Upper New Meadows Lake. Note that these areas of restored intertidal habitat do not consider restoration of additional intertidal habitat in New Meadows Lake above Old Bath Road.

7.2 Discussion of Final Alternatives

7.2.1 Final Alternative 1(Preliminary Alternative 2)

Final Alternative 1 considered the case of a box culvert with a width of 24 ft, or twice that of the existing culvert, with the bottom of the culvert 4.5 ft below that of the existing culvert, and assumes that bedrock outcroppings adjacent to the existing culvert in the lower section of New Meadows Lake would be removed to provide additional flow capacity. Plot P2 in Appendix D shows a profile of this final alternative along the State Road causeway.

Implementation of this final alternative would provide the least restoration benefits of the three Final Alternatives and would result in the restoration of approximately 15 acres of intertidal habitat in Lower New Meadows Lake and approximately 14 acres of intertidal habitat in Upper New Meadows Lake, for a total area of restored intertidal habitat of 29 acres.

7.2.2 Final Alternative 2 (Preliminary Alternatives 4 and 5)

Final Alternative 2 considered the case of a single box culvert with a width of 24 ft and its bottom set 7.5 ft below the invert of the existing culvert. This alternative would be appropriate for installation at a new location along the State Road causeway and would require a substantially longer culvert. The difference between the two Preliminary Alternatives combined in Final Alternative 2 is that Preliminary Alternative 4 assumed that the existing culvert would be removed while Preliminary Alternative 5 retained the existing culvert. The evaluation of the Preliminary Alternatives indicated no difference in the magnitude of restoration benefits associated with these alternatives, and were therefore combined to form Final Alternative 2. A decision whether to remove the existing culvert following construction of the new culvert should consider total costs (i.e., demolition versus long-term maintenance) associated with the existing culvert. Plot P3 in Appendix D shows a profile of this final alternative along the State Road causeway.

Implementation of this final alternative would provide moderate benefits and would result in the restoration of approximately 25 acres of intertidal habitat in Lower New Meadows Lake and approximately 12 acres of intertidal habitat in Upper New Meadows Lake, for a total area of restored intertidal habitat of 37 acres.

7.2.3 Final Alternative 3 (Preliminary Alternatives 3 and 6)

Final Alternative 3 considered the case of a large opening at the State Road causeway suitable for the restoration of full tidal hydrology in Lower New Meadows Lake. The difference between the two Preliminary Alternatives combined in Final Alternative 3 is that Preliminary Alternative 3 considers a culvert while Preliminary Alternative 6 considers a bridge. The evaluation of the Preliminary Alternatives indicated no difference in the magnitude of restoration benefits associated with these alternatives, and were therefore combined to form Final Alternative 3. A decision whether to use a bridge or culvert in the implementation of this final alternative should consider total costs (i.e., implementation and long-term maintenance) associated with a bridge or culvert. Plot P4 in Appendix D shows a profile of this final alternative along the State Road causeway.

Implementation of this final alternative would provide moderate benefits and would result in the restoration of approximately 30 acres of intertidal habitat in Lower New Meadows Lake and approximately 12 acres of intertidal habitat in Upper New Meadows Lake, for a total area of restored intertidal habitat of 42 acres.

8.0 IMPLEMENTATION OF ALTERNATIVES

Final design and construction of a selected alternative would require further analysis. In addition, site-specific factors not evaluated as part of this study could ultimately affect the selection of a suitable design. For instance, geotechnical conditions adjacent to the existing State Road causeway could affect a decision regarding whether a bridge or culvert is the most suitable for this site.

A variety of general considerations associated with implementation of the Final Alternatives were identified as part of this study, including traffic management and the need for additional information required for detailed engineering design. In particular, detailed geotechnical investigations would need to be required to obtain information related to the composition of the existing causeway.

With the exception of Preliminary Alternative 2, tidal exchange during implementation of the Final Alternatives could be maintained using the existing culvert.

8.1 Final Alternative 1 (Preliminary Alternative 2)

Implementation of Final Alternative 1 would require the removal of the existing culvert and the installation of a 24-ft wide box culvert with the bottom of the culvert set 4.5-ft below that of the existing culvert. Complete removal of the existing culvert would be required to implement this alternative due to the reduced culvert bottom elevation. This work and subsequent construction of this alternative would likely require the installation of a temporary coffer dam around the construction area.

Potential issues with the construction of this alternative include the presence of bedrock adjacent to the existing culvert and maintaining tidal exchange during construction. Observed bedrock in Lower New Meadows Lake would likely limit the use of driven sheet-pile for the construction of a coffer dam, necessitating alternative means to dewater the construction area. This alternative would require the removal of bedrock in Lower New Meadows Lake immediately adjacent to the proposed culvert to achieve its' full hydraulic capacity. Observations suggest that the depth of bedrock removal would be between 6 and 10 feet.

Previous work on the existing culvert by the Maine Department of Transportation included provisions to limit restriction of tidal exchange to no more than two consecutive tidal cycles, and similar restrictions would likely be required for the implementation of this alternative. A general approach to achieving this goal would be to build the culvert in two halves. The first half would be built to the west of the existing culvert, allowing for tidal flow through the existing culvert. Tidal flow would be diverted through this half upon its completion, followed by demolition of the existing culvert and construction of the second half of the new culvert. Because this alternative would result in reduced water surface elevations in the lake at low tide relative to existing conditions, this approach might facilitate the removal of adjacent bedrock in the lake following the construction of the culvert.

Because this alternative would discharge ebb flows above Mean Low Water, an apron would be required on the south (seaward) side of the culvert.

8.2 Final Alternative 2 (Preliminary Alternatives 4 and 5)

Final Alternative 2 consist of large openings in the existing causeway with the culvert bottom elevations set approximately at Mean Low Water. The only difference between the two Preliminary Alternatives considered here is that Preliminary Alternative 4 was evaluated with the existing culvert removed while it is retained in Preliminary Alternative 5. Given the similar restoration benefits, the determination of

whether to remove the existing culvert should be based on factors including long-term maintenance costs and the structural integrity of the existing culvert.

A detailed geotechnical investigation (e.g., borings) would be required to evaluate the stability of the existing causeway to fully evaluate this final alternative.

As with the other Final Alternatives, the low invert elevations associated with the associated preliminary alternatives would require dewatering of the construction area, requiring the installation of a temporary coffer dam. Scour protection would require the installation of riprap adjacent to both ends of the culvert for Final Alternative 2.

8.3 Final Alternative3 (Preliminary Alternatives 3 and 6)

Final Alternative 3 consist of large openings in the existing causeway. Given the similar restoration benefits, the selection of a culvert or bridge would likely be determined based on factors, including site suitability, and construction and long-term maintenance costs.

A detailed investigation of the stability of the existing causeway fill would be necessary to fully evaluate this final alternative and the relative merits of a bridge versus a culvert. While the State Road includes a relatively short bridge over the channel between the upper and lower sections of the lake, this bridge was included in the design of the causeway fill. Similar measures were apparently not included during the construction of the causeway that formed New Meadows Lake in the 1930s, and therefore a detailed geotechnical investigation (e.g., borings) would be warranted prior to the selection of a preferred approach for this final alternative.

The low invert elevations (approximately Mean Lower Low Water) associated with this alternative would require dewatering of the construction area, subsequently requiring the installation of a temporary coffer dam.

Final Alternative 3 would likely require scour protection and installation of riprap adjacent to both ends of the culvert, each end of the bridge, and on the slopes between the bridge abutments and the underlying channel.

8.4 Probable Opinion of Costs

A probable opinion of costs was developed for the three Final Alternatives. These costs include items associated with design, permitting, and construction. Costs associated with stabilization of the channel under the US Route 1 causeway between the upper and lower sections of New Meadows Lake are also included. “Low” and “High” values are presented for the costs associated with each of the Final Alternatives to account for cost variability associated with factors, such as variability of work associated with each final alternative (e.g., Final Alternative 3 considers both a bridge and a culvert) and unknown factors that would be addressed as part of a detailed design. The “Low” and “High” values are assumed to represent general lower and upper-ranges of costs for each of the items. Contingency costs are not included.

Table 5: Probable Opinion of Costs

Final Alternative No.	1		2		3		Notes
Preliminary Alternative No.:	2		4, 5		3, 6		
Design	Low	High	Low	High	Low	High	
Site Investigation	\$20,000	\$30,000	\$30,000	\$50,000	\$40,000	\$70,000	
Design	\$40,000	\$60,000	\$60,000	\$100,000	\$100,000	\$250,000	1
Permitting							
Permitting	\$25,000	\$50,000	\$80,000	\$120,000	\$100,000	\$200,000	2
Construction							
Mobilization/Site Prep	\$25,000	\$40,000	\$30,000	\$50,000	\$40,000	\$70,000	
Construction	\$150,000	\$300,000	\$500,000	\$1,000,000	\$1,250,000	\$3,500,000	3
Total	\$260,000	\$480,000	\$700,000	\$1,320,000	\$1,530,000	\$4,090,000	

Notes: 1) Includes construction oversight.

2) Assumes project benefits mitigate project affects on natural on regulated natural resources.

3) Includes removal of existing culvert where required.

The basis of these probable opinions of cost is best professional judgment without knowledge of site-specific factors affecting potential project costs. In general, the values presented should be used in conjunction with the potential benefits associated with the Final Alternatives to evaluate the relative merits of the evaluated alternatives.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

All of the Final Alternatives would restore substantial areas of intertidal habitat in Lower New Meadows Lake. As discussed in Section 7.1.3, the potential for restoration of intertidal habitat in Upper New Meadows Lake is limited by the geometry of the channel under the US Route 1 Bridge. Barring this restriction, areas of restored intertidal habitat would greatly increase in Upper New Meadows Lake. Note that these areas of restored intertidal habitat do not consider restoration of additional intertidal habitat in New Meadows Lake above Old Bath Road.

Firm conclusions regarding potential improvements to water quality in the lake were not determined, and would require additional data on existing water quality and hydrodynamic conditions in the New Meadows River. In general, increasing tidal exchange in the lake will result in improved water quality. The volume of tidal exchange and increased tidal range associated with Final Alternative 3 would provide the best opportunity to prevent the formation of stratified conditions in Lower New Meadows Lake. Following on this, there is a high likelihood that water quality would also improve in Upper New Meadows Lake. A definitive evaluation of benefits to water quality would need to consider changes in water properties (e.g., temperature) in New Meadows River well downstream from the State Road causeway.

Primary constraints on the implementation of the Final Alternatives include socio-economic factors and cost. Identified socio-economic factors include those related to the creation of intertidal conditions in New Meadows Lake and potential effects to the marina immediately south of the State Road Causeway. While the marina would likely benefit from a reduction in foam formation, currents during ebb and flood tides could affect docks and navigation in the New Meadows River.

9.2 Recommendations

Further investigation of water temperatures in the New Meadows River are recommended to provide information for the evaluation of coupled-effects associated with increased tidal exchange between the river and New Meadows Lake. Information collected as part of this study is not sufficient to determine the potential for improved water quality in the lake due to a lack of information on water quality parameters, specifically temperature in the river. Because water quality problems in the lake are associated with stratification during summer, it is recommended that vertically-stratified water temperature data be continuously recorded in the New Meadows River between the State Road causeway and a to-be-determined seaward location. A general recommendation is that the southern, or seaward, limit of data collection would be in the vicinity of Thomas Bay along the New Meadows River in Brunswick.

A final recommendation is that alternative schemes be considered for mitigation of water quality problems in New Meadows Lake. While the Final Alternatives are considered practical, the magnitude of the projects would require a drawn-out planning process. Water quality problems will likely persist during this process and continue to adversely affect resources in New Meadows Lake.

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