Results and Conclusions -- Killearn Chain of Lakes Hydrologic Investigation

PREPARED FOR: City of Tallahassee
WRE Stormwater Management

PREPARED BY: Richard Morrison
Richa Srivastava
Mitchell L. Griffin

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Contents

Introduction

This study investigated the water levels in the Killearn Chain of Lakes (KCOL) during non-flood conditions, with a goal of identifying alternatives to maintain water levels in the lakes for longer periods of time than with current conditions. An update and modification of the Flood Insurance Study (FIS) effective computer model was used to analyze lake levels in Lake Kinsale, Lake Killarney, and Lake Kanturk (the chain of lakes, listed from upstream [west] to downstream [east]). The subdivisions surrounding the KCOL were developed in the 1970s and the lakes are privately owned and operated by the Killearn Homes Association (HOA).

The City of Tallahassee initiated this study to evaluate the hydrologic response of the water levels in the lakes after the culverts between the lakes were modified around 1997 to reduce flooding. The two main questions that were investigated were:

1. Did replacing the culverts in the late 1990s cause the lakes to drain faster and lower?
2. Can more stormwater be retained to effectively raise the water levels in the KCOL? Any action is restricted to not raising flood stages to elevations that could potentially create damage to the properties surrounding the lakes.

This memorandum provides a summary of the findings, background information, and a description of the evaluation.

Summary of Findings

This investigation used information found primarily in design and as-built drawings and the hydrologic computer model used to establish the regulatory floodplain in the KCOL to determine the impact of previous City projects on the water levels. Citizens have complained that the water levels fluctuate too much and the lakes have gone to near dry, or to dry in the east, during recent years. This investigation is primarily a desktop study to determine alternatives that may increase the water levels in the lakes over a period of time. Any alternative is required to not causing worse flooding conditions.

This study determined that there is substantial groundwater percolation affecting water levels in the two downstream lakes, Lake Killarney and Lake Kanturk. Lake Kanturk appears especially “leaky” during dry years and there is visual evidence of potential groundwater conduits (pre-sinkholes). Because of relatively deep overburden soils, an open sinkhole may not form, but soft sand or lack of confining layers under the lakes may allow seepage at spot locations. Groundwater percolation is occurring in Lake Kinsale too, but it has a large contributing watershed with a baseflow that keeps its levels higher during dry periods. The previous project’s weir at the outlet of Lake Kinsale also assists in maintaining water in the lake during dry years. Therefore, the study focused primarily on alternatives to increase water levels in the two downstream lakes, Killarney and Kanturk.

While the conceptual projects presented in this study do reduce the impact of dry periods on the lakes’ water levels, they do not completely stop the reduction of water levels during dry weather. Completely sealing all three lakes would nearly accomplish that goal, but this is apparently unnecessary. The conceptual projects looked at retaining water by either lining all or some of Lake Kanturk; isolating Lake Killarney from Kanturk, where it appears to be more susceptible to groundwater seepage; and adding supplemental water presumably from re-establishing wells previously used to supplement the lakes. The following table provides a summary of the conceptual projects evaluated.

Conceptual Project	Effect on Lake Killarney Water Levels (ft)	Effect on Lake Kanturk Water Levels (ft)	Anticipated Difficulty in Permitting	Project Construction Cost Opinion and Range
Line all of Lake Kanturk	Up to 4 feet higher during droughty periods	About 5 feet higher during droughty periods	High	$7,900,000 typical, $5,100,000 to $11,900,000 range
Line half of Lake Kanturk	About 1 foot higher during droughty periods	About 4 feet higher during droughty periods	Medium	$3,800,000 typical, $2,500,000 to $5,700,000+ range
Isolate Lake Killarney from Kanturk with a Weir	About 1 to 2 feet higher during droughty periods	May reduce levels slightly quicker without upstream water	Low	$83,000 typical, $54,000 to $124,500 range
Rehabilitate well(s) for supplemental water to Lake Killarney (1 million gallons per day)	About 2 feet higher during drought	Slows reduction during dry years	High	$31,000 typical, $20,000 to $46,500 range

Droughty periods may be natural seasonal dry periods, like late spring and fall, or over longer time periods with reduced precipitation.
Lining Lake Kanturk costs depend highly on haul distance to obtain suitable material.

These conceptual projects would need further development if pursued. Some of the assumptions made were based on visual evidence and inferred percolation rates. Additional data gathering is warranted for better calibration of the computer model used in this study; and for improving the cost estimate, feasibility and effectiveness of the projects. However, there is no need to collect additional field data until there is consensus on which project alternatives should be pursued.

Background Information

KCOL refers to three lakes that are adjacent to one another, separated primarily by road crossings with culverts under the road. Prior to 1970, the lakes were part of a rural area. The former farm owner ditched the low spots to improve drainage and actually planted crops in Lake Killarney's bottom during some dry periods (Bray, 2013). However, the lake beds are expected to be flooded most of the time because the KCOL are the low spot for a large contributing drainage area (Figure 1). Various methods have been used to identify the extents of the watershed contributing runoff to the KCOL. Some methods ignore sub-basins that have less than a 1 percent chance of discharging in any given year; therefore, acreages may differ among reports based upon the author's method for delineating contributing drainage basins. About 9,795 acres drain to the three lakes, with 42 percent entering the upstream ditch leading to Lake Kinsale and the remaining contributing area divided among the three lakes. Additional specific data are provided herein.

FIGURE 1
April 2013 aerial view of the KCOL when the lakes are nearly full
(left to right: Lake Kinsale, Lake Killarney, and Lake Kanturk)
Killearn Chain of Lakes Hydrologic Investigation

During development of the area into residential land use, the developer installed groundwater pumps at the east end of Lake Kinsale and at the tip of the peninsula in Lake Kanturk to keep the lakes hydrated during droughty seasons and years (Bray, 2013). With time, the pumping was discontinued, probably resulting from the cost associated with operation and maintenance. The Killearn Estates and surrounding neighborhoods were annexed into the City, but the ownership of the lakes was not transferred and the HOA still has maintenance responsibilities. The City is responsible for water quality impacts from discharges from the storm sewer system and is the delegated local manager of the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP). The entire KCOL is regulated under the NFIP and the flood insurance maps include these lakes.

As is the case in many urban areas, lands of rural nature are developed in stages. It was not uncommon for the drainage infrastructure, which might have never been intended to provide flood control for urban use, to become overwhelmed by increased runoff rates and volumes. The neighborhoods adjacent to the KCOL were experiencing flooding which led to a Northwest Florida Water Management District (NWFWMD) evaluation of the culverts serving the roads separating the lakes in 1985 (Maristany, 1985). Additional evaluations were done (CDM, 1993) and designs completed in 1994 for Leon County (CDM, 1994). By 1997 new culverts were constructed and flood impacts were greatly reduced.

After the flood improvements were implemented and after supplemental groundwater addition was stopped, the region has experienced reduced rainfall totals. The long-term average rainfall for Tallahassee is about 62.6 inches per year (in/yr), evaporation/transpiration has been reported to be about 42 to 49 in/yr, leaving a net precipitation of around 20 in/yr (Odom Springs Institute, 2011; Chelette, Pratt, and Katz, 2002). Between 1998 and 2000, the annual rainfall was about 10 in/yr below average (Chelette, Pratt, and Katz, 2002), and there has been several significant low rainfall years since then. The KCOL water levels have also varied between full to nearly dry during these cycles (compare Figure 1 to Figure 2 below).

FIGURE 2
November 1998 aerial view of the KCOL when the lakes are nearly dry
Killearn Chain of Lakes Hydrologic Investigation

The Killearn region is located northeast of downtown Tallahassee in a region characterized as the lakes region by Chelette, Pratt, and Katz (2002). The groundwater is semi-confined from the surface with a layer of Hawthorne clayey soil that generally separates the lakes from the lower zones. In 2008 the Upper Floridan groundwater potentiometric level around this area was near elevation 40, while the lake bottoms are closer to elevation 70. This means that there is a natural potential for groundwater recharge in this area, subject to the permeability of the various soil layers or any other potential sinks or direct connections to the groundwater aquifer. The regional recharge in the region was reported to range around 8 in/yr (Odom Springs Institute, 2011). Chelette, Pratt, and Katz (2002) noted that in addition to the low rainfall, the groundwater levels were near record lows when the aerial photograph shown in Figure 2 was taken:

> *"Water levels in the Floridan and Intermediate aquifers experienced period-of-record (1966 - 2001) lows during the study period (Figures 6 and 7).*[figures are in referenced document only] *Water levels in both aquifer systems mirror the cumulative departure from normal, rising in relatively wet periods and declining when it is dry. During the extreme dryness of 2000, ground water levels declined to elevations not seen for more than 30 years, and likely not since the 1950s."*

If fully confined, then the Florida aquifer groundwater levels will have a lower influence on the lake water levels in the KCOL. However, the degree of confinement is unknown and it would be difficult to determine this unless an obvious sinkhole is documented. The connectivity to the groundwater is further discussed below.

PBS&J (now Atkins North America, Inc.), under contract with the City, developed a regulatory hydrologic/hydraulic FIS model for use in the FEMA flood insurance program. CH2M HILL recently updated the 2001 computer model to work on the City's current computer software, XPSWMM 2012 (CH2M HILL, 2013). Only minor changes were made to the program's hydrology input to account for some development that has occurred since 2001, primarily along Thomasville Road. This program was utilized to evaluate the rainfall and runoff from the contributing watershed and then evaluate some hypothetical scenarios that could retain more stormwater in the KCOL.

Existing Conditions

The structures (culverts and/or weir) in the drainage system that regulate storm discharges and establish normal water levels in the KCOL are summarized in Table 2 for both the existing and former (historical) conditions. The former pipe culverts were replaced with large box culverts to reduce flooding of residences, properties, and roadways around Lake Kinsale. The new box culverts between Lake Kinsale and Killarney have great capacity because Lake Kinsale is relatively small and it has a large contributing drainage area, so Lake Kinsale does not provide much storage to dampen downstream peak flow rates. Prior to the culvert upgrades, the invert of the culverts established the normal elevation of the lakes (the normal elevation or level of the lakes is also called the control elevation by engineers when structures are present). There is a weir constructed in front of the triple box culvert at Lake Kinsale that keeps the control elevation of the water level higher than the invert of the culverts. Also, it should be noted that the weir has a slot with a gate that remains closed and is only opened to lower water levels in Lake Kinsale when needed for maintenance activities. The current control elevation of Lake Kinsale is higher than the elevation of the historical structures (even if the slot were open). Since the two other lakes are interconnected without a control structure, the higher downstream control elevation at Lake Kanturk affects the upstream Lake Killarney levels.

Currently, Lake Killarney's culvert invert is 71.1, which is 3 feet lower than the downstream invert elevation at Lake Kanturk (74.1), (note all elevations presented in this report are based upon the National Geodetic Vertical Datum of 1929, NGVD29). Therefore, the control elevations for Lake Killarney and Lake Kanturk are the same and are set by the downstream culvert inverts under Centerville Road at elevation 74.1. The control elevation of Lake Kinsale is set by the weir at West Shannon Lake Drive at 75.5. However, if the gate in the Lake Kinsale weir is removed (slot opened) then the control elevation of Lake Kinsale would be the same elevation as the other two lakes (elevation 74.1). Prior to the culvert upgrades, the lowest control elevation was at Lake Kanturk, which was 73.9. Therefore, the overall control elevation of the lakes is slightly higher now (by 0.2 foot, or about 2.5 inches). Even though the invert elevations of the Lake Killarney culvert (were lowered with the new box structures (by about 1.6 feet), the lake's level would not be lowered because the downstream structure establishes upstream normal water levels.

This control elevation discussion is valid when the lakes are full enough to be flowing through all three lakes' structures. The control elevations are attained within a short time after a moderate storm event (days) and would remain there if there were no losses. There are losses in the system, though, through evaporation and seepage. When the losses exceed the baseflow, which is the slow release of near surface groundwater from the upstream creeks and watershed, then the lake levels drop below the control elevation. As noted previously, this has often been the case, and at times, levels are significantly below the control elevations.

Figure 3 provides a chart of the lake areas versus elevation data. From this chart it is apparent that Lake Kinsale is much smaller than the other two. Table 3 provides the chart data in tabular format, with areas interpolated from LiDAR data (light detection and ranging or laser imaging, detection and ranging). At elevation 75 (when water is flowing through the lake system), Lake Kinsale is about 14 acres, Lake Killarney is about 85 acres and Kanturk is about 85.5 acres. As water levels recede, the area of Lake Kanturk reduces more quickly than Lake Killarney because Kanturk has a very flat shape.

TABLE 2
Summary of Elevations in Lakes that Affect Low Water Levels
Killearn Chain of Lakes Hydrologic Investigation

Lake	Downstream Road Crossing	Existing (Current) Structure Type	Invert EL (ft NGVD29)	Control EL (ft NGVD29)	Previous (Historical) Structure Type	Invert EL (ft NGVD29)	Control EL (ft NGVD29)
Kinsale	W. Shannon Lakes Drive	Triple Box Culvert, 8-ft x 10-ft	71.5		36-in CMP	73.4	73.9
		Weir (in front of culvert)	75.5	75.5	36-in CMP	73.4	
		3-ft wide slot in weir with a manual gate	74.0				
		Roadway crest	82.2		Roadway crest	82.2	
Killarney	Shannon Lakes Drive East	Double Box Culvert, 8-ft x 10-ft	71.1	74.1	66-in CMP	72.7	73.9
		Roadway crest	81.6		Roadway crest	83	
Kanturk	Centerville Road	Double Box Culvert, 8-ft x 10-ft	74.1	74.1	48-in RCP 36-in RCP 24-in CMP	73.9 75.75 79.2	73.9
		Roadway crest	82.3		Roadway crest	82.3	

EL = elevation; RCP = reinforced concrete pipe; CMP = corrugated metal pipe; NGVD29 is the vertical datum of the elevations.
Invert elevations are from the XPSWMM model, verified by construction drawings, rounded to the nearest 0.1 ft.

FIGURE 3
Lakes Area Variation with Elevation
Killearn Chain of Lakes Hydrologic Investigation

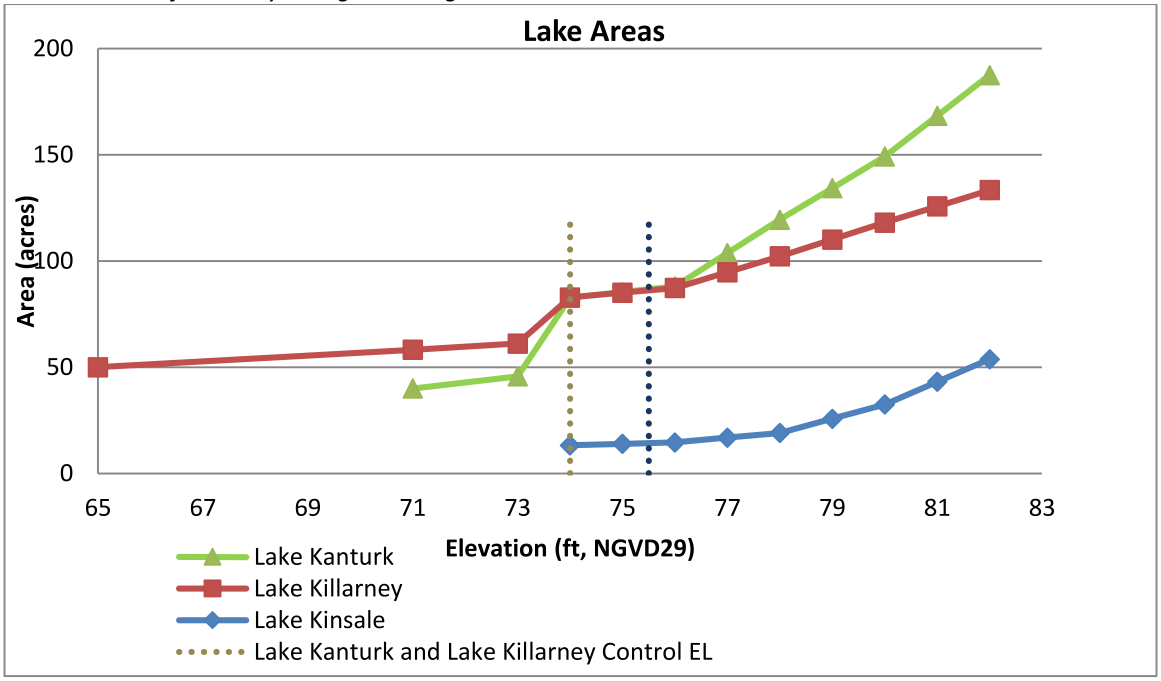

TABLE 3
Tabular Data Interpolation of Area per Elevation from LiDAR Data
Killearn Chain of Lakes Hydrologic Investigation

Elevation (ft, NGVD29)	Lake Kinsale (ac)	Lake Killarney (ac)	Lake Kanturk (ac)
65	--	50.0	--
71	--	58.2	40.0
73	--	61.2	45.7
74	13.3	82.9	82.8
75	13.95	85.1	85.45
76	14.6	87.3	88.1
77	16.85	94.75	103.8
78	19.1	102.2	119.5
79	25.8	110.15	134.35
80	32.5	118.1	149.2
81	43.15	125.75	168.4
82	53.8	133.4	187.6

LiDAR data available at greater than elevation 74. Lower elevations in this table are from original XPSWMM model.

The total drainage basin area for the three lakes is about 9,795 acres, upstream of Centerville Road. Almost 4,000 acres is from west of Thomasville Road, draining to Lake Kinsale. Table 4 contains a summary of the contributing areas. Lake Kinsale has a total contributing drainage area (including the lake) of about 5,639 acres. This means that the ratio of drainage area to lake area is about 424:1 at lake elevation 74. Lake Killarney has the smallest direct contributing area of only 1,156 acres, but the Lake Kinsale drainage will add to the overall contributing area for a drainage area per lake area ratio of about 82:1. The drainage area to lake area ratio for Lake Kanturk is 118:1. Therefore, stormwater runoff entering Lake Kinsale will quickly fill the lake and overflow into Lake Killarney. Since the control elevation of the two eastern lakes is tied together and controlled downstream of Lake Kanturk (i.e., at Centerville Road), Killarney and Kanturk lakes would fill almost simultaneously.

The ratio of the contributing drainage area to lake area is more indicative of the potential effect that baseflow seepage from the surficial groundwater draining from the uplands would have on each lake. Lake Kinsale has a relatively large drainage area that could contribute seepage into the streams during dry seasons. Lake Killarney has the least amount of contributing drainage area feeding baseflow directly into it and, thus, has the least opportunity to stay hydrated among the three lakes.

TABLE 4
Contributing Drainage Areas per KCOL Lake
Killearn Chain of Lakes Hydrologic Investigation

Lake	**Contributing Drainage Area (ac)**
Kinsale	5,639
Upstream	*4,112*
North and South	*1,527*
Killarney	1,156
Kanturk	3,000

Source: Best estimate by CH2M HILL digitized from CDM (1993) figure of basin boundaries.

If it is dry and the lakes are low, then only direct rainfall would effectively raise water levels until the landscape ceases to absorb the moisture and stormwater runoff routes through the storm system to the primary streams feeding the lakes. By using Table 3 areas, the volume of the water in the lakes for each elevation was computed using the prism method and the estimates are shown in Table 5. Being smaller and having a very large contributing watershed draining to Lake Kinsale first, runoff would raise that lake's levels first. Less than 0.01 inch of runoff from its entire contributing area could raise Lake Kinsale water level by 1 foot. At elevation 71, it takes about 325 acre-feet (ac-ft) of water to raise Lake Killarney 1 foot. With a contributing drainage area of about 6,800 acres, that is less than 0.6 inch of runoff, assuming Lake Kinsale was at its control elevation. However, runoff water will be shared with Lake Kanturk when Killarney is above elevation 71.1. The combined volume of water to raise both lakes by 1 foot is closer to 445 ac-ft. With the extra contributing drainage area from Lake Kanturk, that combined volume requires about 0.54 inch of runoff to raise both lakes 1 foot. But there are losses and storage areas to fill prior to runoff occurring, so a rainfall event much larger than 0.6 inch would be required during dry periods to significantly raise the two downstream lakes' levels by a foot or more.

TABLE 5
Tabular Data Interpolation of Volume per Elevation from LiDAR Data
Killearn Chain of Lakes Hydrologic Investigation

Elevation (ft, NGVD29)	Lake Kinsale (ac-ft)	Lake Killarney (ac-ft)	Lake Kanturk (ac-ft)
71	0.0	324.6	120.0
73	0.0	444.0	205.7
74	6.7	516.1	270.0
75	20.3	600.1	354.1
76	34.6	686.3	440.9
77	50.3	777.3	536.8
78	68.3	875.8	648.5
79	90.7	981.9	775.4
80	119.9	1096.1	917.2
81	157.7	1218.0	1076.0
82	206.2	1347.6	1254.0

The lake elevations are significant not only for recreational purposes, but also as part of the regulated floodplain. The previous structural improvements were implemented to reduce flooding impacts and so the elevations of the nearby residences and lots are of importance. The data provided in the most recent evaluation were reviewed and are summarized in Table 6. These data were presented in the 1993 evaluation and, while the hydraulic information is outdated, the first floor elevations (threshold) of potential residences affected by flooding are likely the same. These data were presented in the 1993 evaluation and, while the hydraulic information is outdated, the first floor elevations (threshold) of potential residences affected by flooding are likely the same. Generally, most residences that were previously flooded have their living floor elevation at about elevation 81. But there are a few homes that could be flooded with elevations as low as 79.2. Any changes to water levels must not raise the potential for flooding these residences. The banks of the lakes are around elevation 74, but most of the yards around Lake Kinsale and Kanturk are at elevation 76. Lake Killarney has the most low yard elevations around the lake. Attachment A provides maps with the approximate contours highlighted for reference.

TABLE 6
Elevations of Residences and Yards Adjacent to the Lakes
Killearn Chain of Lakes Hydrologic Investigation

Lake	Number of Structures with Threshold Less than EL 81 ft NGVD29	Lowest Structure Threshold EL (ft, NGVD29)	Approximate Yard EL (ft, NGVD29)
Kinsale	2	78.9	76
Killarney	2	79.2	About 50% >74 and less than 75; rest between 75 and 76
Kanturk	2	79.2	76

Source: CDM, 1993

Evaluation with FEMA Model

The XPSWMM simulation model is a program that estimates runoff, flow rates, and water levels given precipitation input data. Runoff is estimated as precipitation excess after infiltration. The standard SWMM Runoff method was applied with infiltration predicted based on Horton's Equation. Rainfall simulated was for both design storms and 1-year continuous simulations. The short duration (8 hour) intense design storms are important to evaluate peak flood conditions, while longer continuous simulations are useful in seeing how the water levels in the lakes respond over a dry and wet season.

The original scope of services included single event simulations of the 5-year, 10-year, 25-year, and 100-year frequency 8-hour duration FDOT design storms to evaluate the potential for flooding. Continuous simulations were conducted using 15-minute rainfall data from 1982, as provided by the City, which is representative of an average rainfall year. The default evaporation rate of 0.1 inch per day was used for the continuous simulations.

Two conditions were studied, the original culvert system prior to improvements (called the historical conditions) and the current culvert system (existing conditions). Survey data from the following sources were used to determine the historical conditions:

- Existing conditions survey of the Shannon Lakes Drive West culvert dated 8/28/94
- Existing conditions survey of the Shannon Lakes Drive East culvert dated 8/28/94
- Construction plans for Centerville Road culvert replacement dated December 1995
- As-built survey of the Shannon Lakes West culvert crossing dated 11/07/96
- As-built survey of the Shannon Lakes East culvert crossing dated 11/20/96
- As-built survey of the Centerville Road culvert replacement dated 1/15/97

In addition to the culverts, there were some farm road crossings downstream of Centerville Road that were modified as part of the Centerville Road culvert replacement. The KCOL model was extended to include the watershed downstream to the end of the improvements so any backwater constraints from downstream would be included in the historical conditions model. Although these crossings were included in the historical and existing conditions models, they did not affect the water levels up to Centerville Road and do not warrant further discussion.

The changes to the model were completed and a historical conditions model constructed as discussed above. Using the updated model, different simulations were conducted as described above. Upon review of the preliminary results, the City requested additional continuous simulations to be conducted for two additional time periods: 1986 to 1987 and 1989 to 1990. 1982 was considered an average year with 60.1 inches of rainfall. 1986 to 1987 had a dry spring followed by a wet summer, with 72.9 inches of rainfall. 1989 to 1990 was a more typical wet year with 65.2 inches of rainfall.

The initial alternatives examined were trying to raise the control elevations in the three lakes as shown in Table 7 by installing new weirs. Lake Kinsale's control elevation is managed by a weir structure. Similar types of structures were envisioned downstream, so a range of control elevations were included. For example, one option hypothesized was if Lake Kinsale's slot was left open and the downstream control elevations were raised, then maybe more water could be retained downstream (Alternatives 1 and 2). Alternatives 3 looked at raising only Lake Killarney's control elevation.

The results of these simulations indicated that:

- The difference between the historical and current conditions was negligible. However, normal water elevations (control elevations) were slightly elevated in the current condition versus the historical condition, except for peak stages which were significantly reduced.
- The FEMA model indicated that there would be enough stormwater available during dry times and that adding new weir structures would keep lake levels higher.

- In general, the design storm peak elevations did not significantly increase with the insertion of new weir structures to a point that cause impacts to properties. The predicted changes were only a couple of inches higher with weirs set 1-foot higher than current control elevations.

TABLE 7
Initial Scenarios Simulated for KCOL
Killearn Chain of Lakes Hydrologic Investigation

Alternatives	Lake Kinsale Structure Invert EL	Lake Killarney Structure Invert EL	Lake Kanturk Structure Invert EL
0. Current Conditions	74.0	71.1	74.1
1. Raise Control Elevation in Downstream Lakes Moderately	74.0	73.0	75.0
2. Raise Downstream Lake Even Higher than Middle Lake	74.0	73.0	76.0
3. Raise Middle Lake Only	75.5	75.0	74.1

EL = elevation NGVD29.
Elevations based on as-built survey with elevations listed rounded up to near 0.1 ft.
Lake Kinsale has a slot opening that is typically closed, so the control elevation there is EL 75.5.

Figures 4 through 6 illustrate the lakes results for the continuous simulation for 1982. These charts illustrate that the lake levels pretty much tracked the elevations of the weirs. Based on these model results, one would conclude that there were no impact on low lake levels from previous structural changes made to reduce flooding and that a combination of new weir structures in front of the box culverts would successfully increase water levels. However, it was evident that the FEMA model was not reproducing observed lake behavior. This is because the FEMA flood model was constructed for simulating flood impacts, and not long term simulations. For flood control the emphasis is on the peak impacts under wet conditions during very intense storms. The main topic evaluated in this study, though, depended more on long-term performance during dry seasons or dry years. Therefore, additional modifications to the model were warranted.

Additional Investigations with Potential Groundwater Losses

The main issue with the FEMA model was that it did not predict reductions in water levels between rain events (inter-event simulation) because the losses from the lakes were not being simulated. Evaporation data from regional sites were reviewed to select an appropriate value. Actual evaporation rates vary with weather pattern (including temperatures, wind, and radiation intensity), surrounding land use, and waterbody depth and area. Different references will vary depending on the method of estimating or monitoring evaporation rates or the period of record reported. Monthly evapotranspiration (ET) rates were changed to reflect the seasonal change and make ET loss to be 49 inches per year (in/yr), which is what IFAS reports as high potential evapotranspiration (PET) rates for Tallahassee (90% PET; IFAS 1984). Even at this higher PET loss rate, this loss corresponded to less than 1 cubic foot per second (cfs) on an average annual daily flow (AADF) basis (about 0.5 million gallons per day [mgd]) when the lake areas are at their respective control elevation. Wet and average years should have lower annual lake ET losses; closer to 45 to 47 in/yr, which would not cause a significant difference in the lake level results (i.e. 49 in/yr versus 45 in/yr).

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FIGURE 4A
Lake Kinsale Simulations using the FEMA KCOL Model for Historical and Current Conditions
Killearn Chain of Lakes Hydrologic Investigation

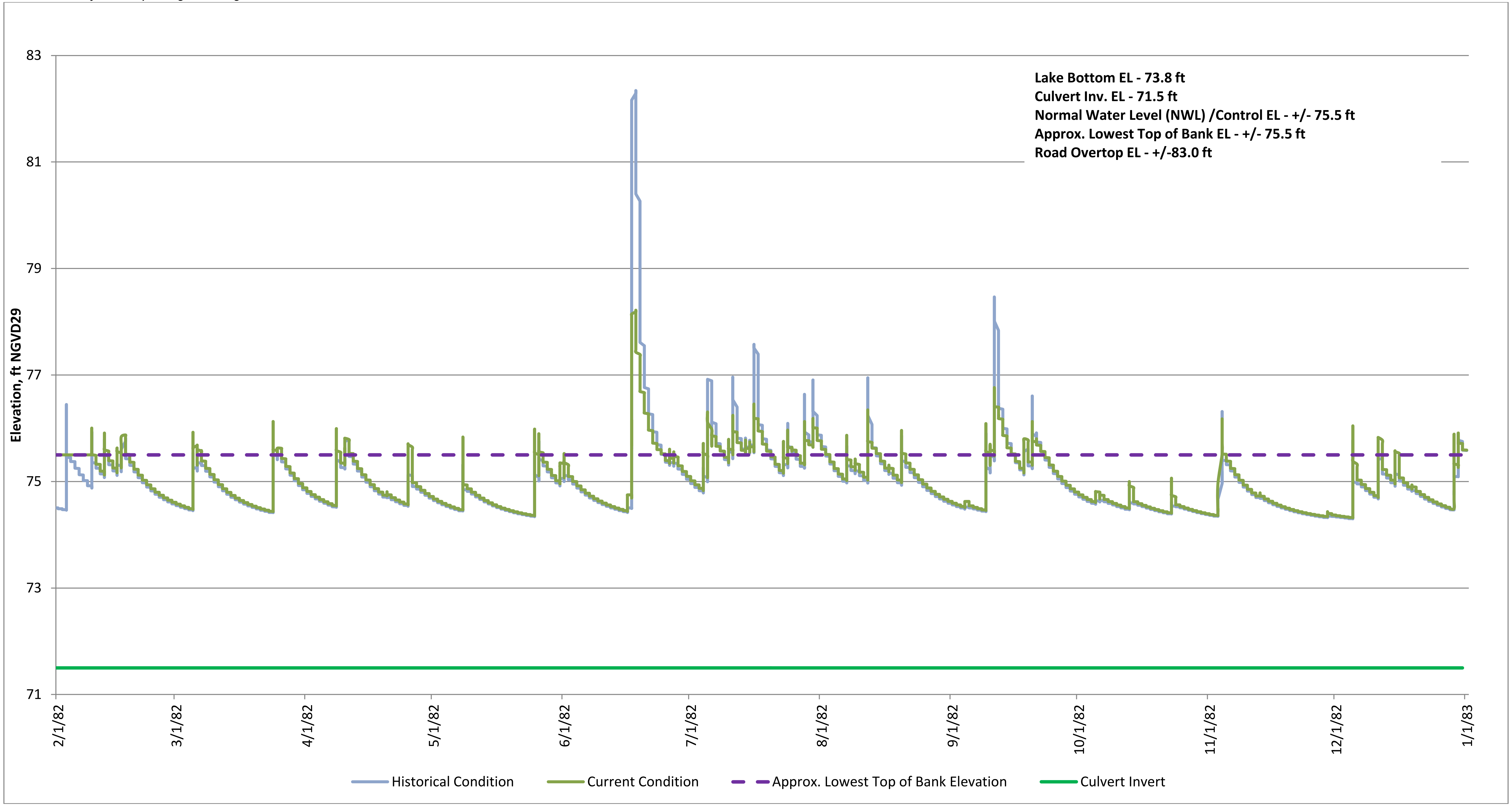


FIGURE 4B
Lake Kinsale Simulations using the FEMA KCOL Model for Current Condition and Proposed Alternatives
Killearn Chain of Lakes Hydrologic Investigation

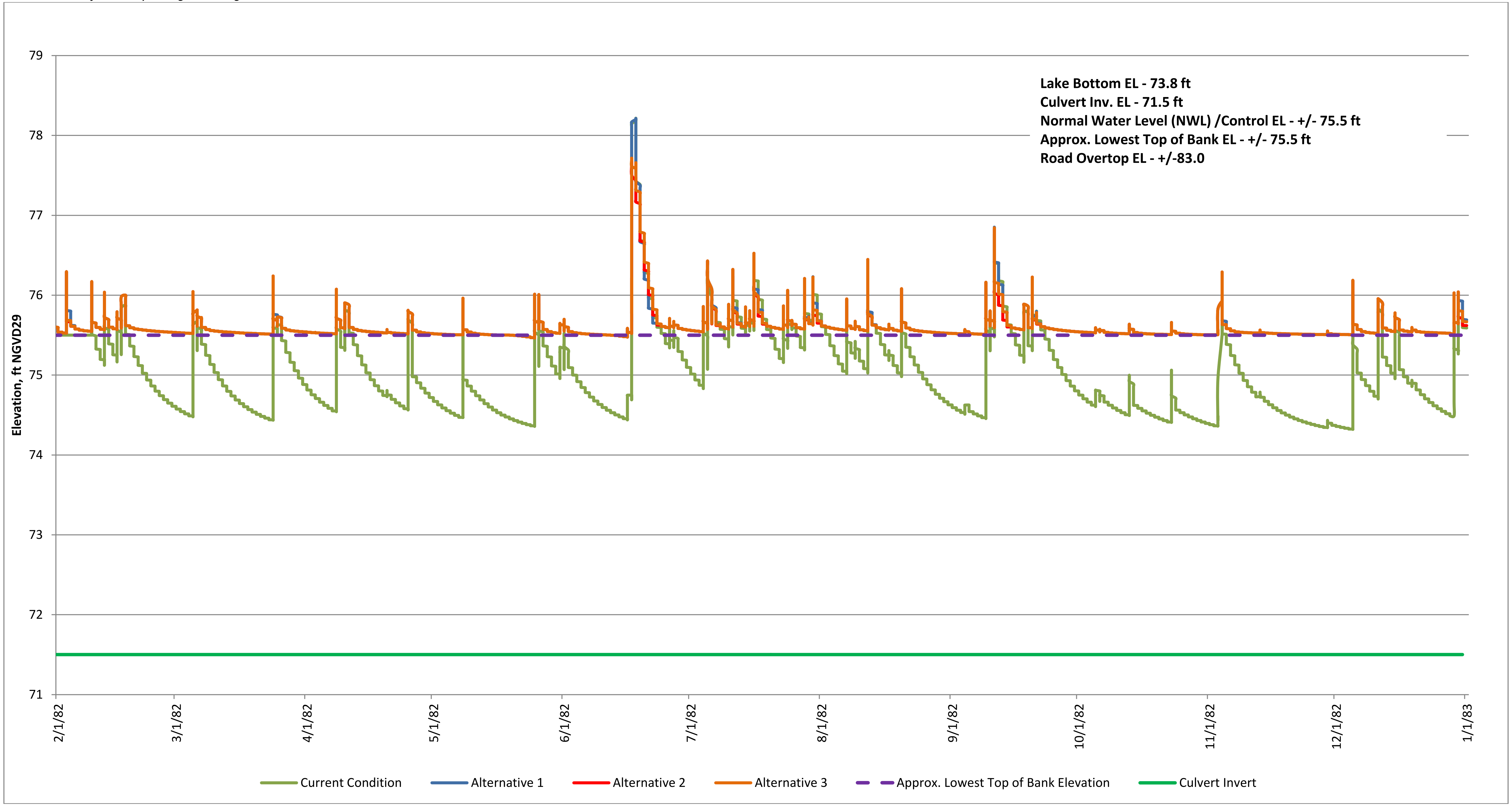


FIGURE 5A

Lake Killarney Simulations using the FEMA KCOL Model for Historical and Current Conditions

Killearn Chain of Lakes Hydrologic Investigation

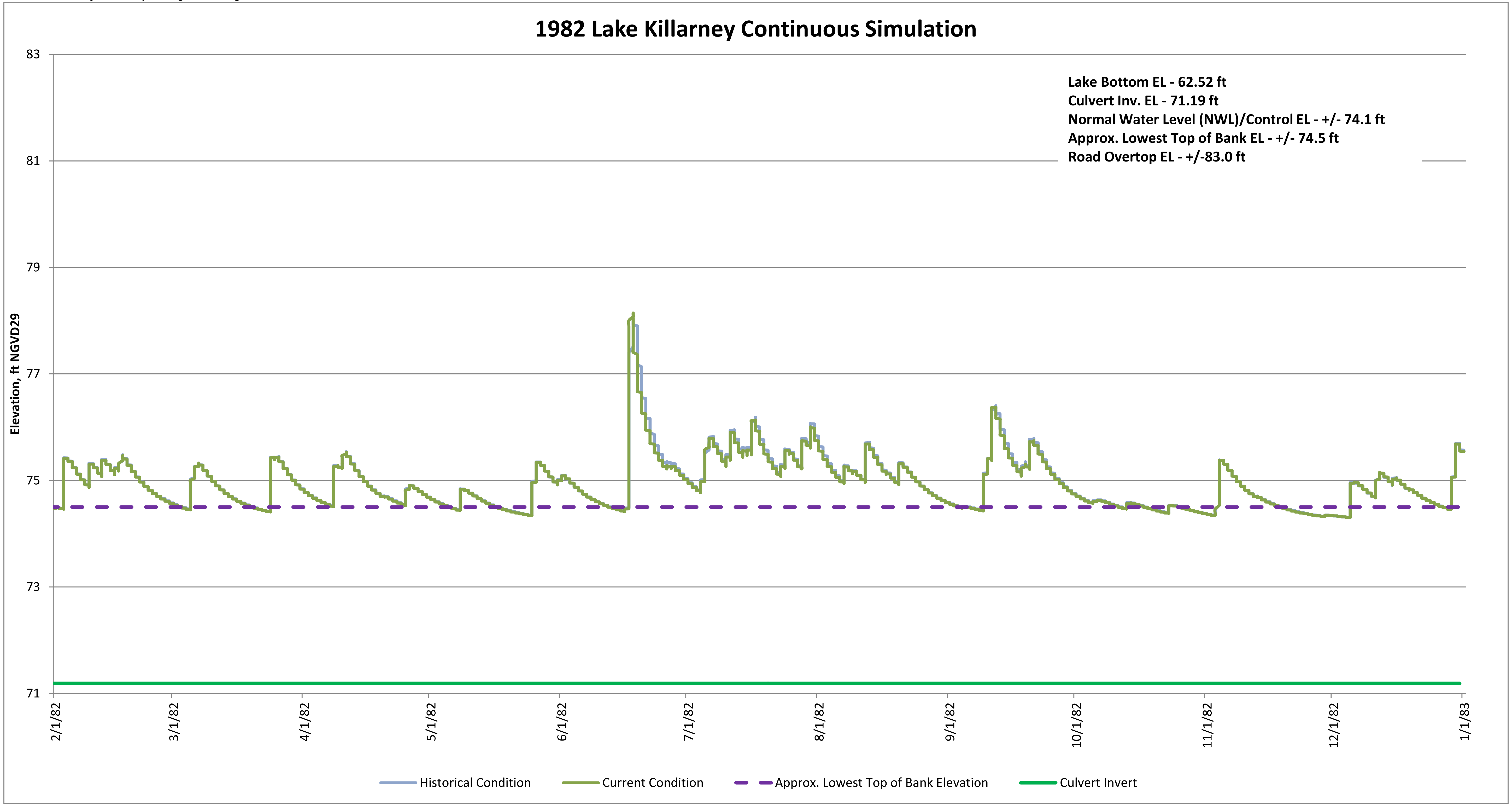


FIGURE 5B
Lake Killarney Simulations using the FEMA KCOL Model for Current Condition and Proposed Alternatives
Killearn Chain of Lakes Hydrologic Investigation

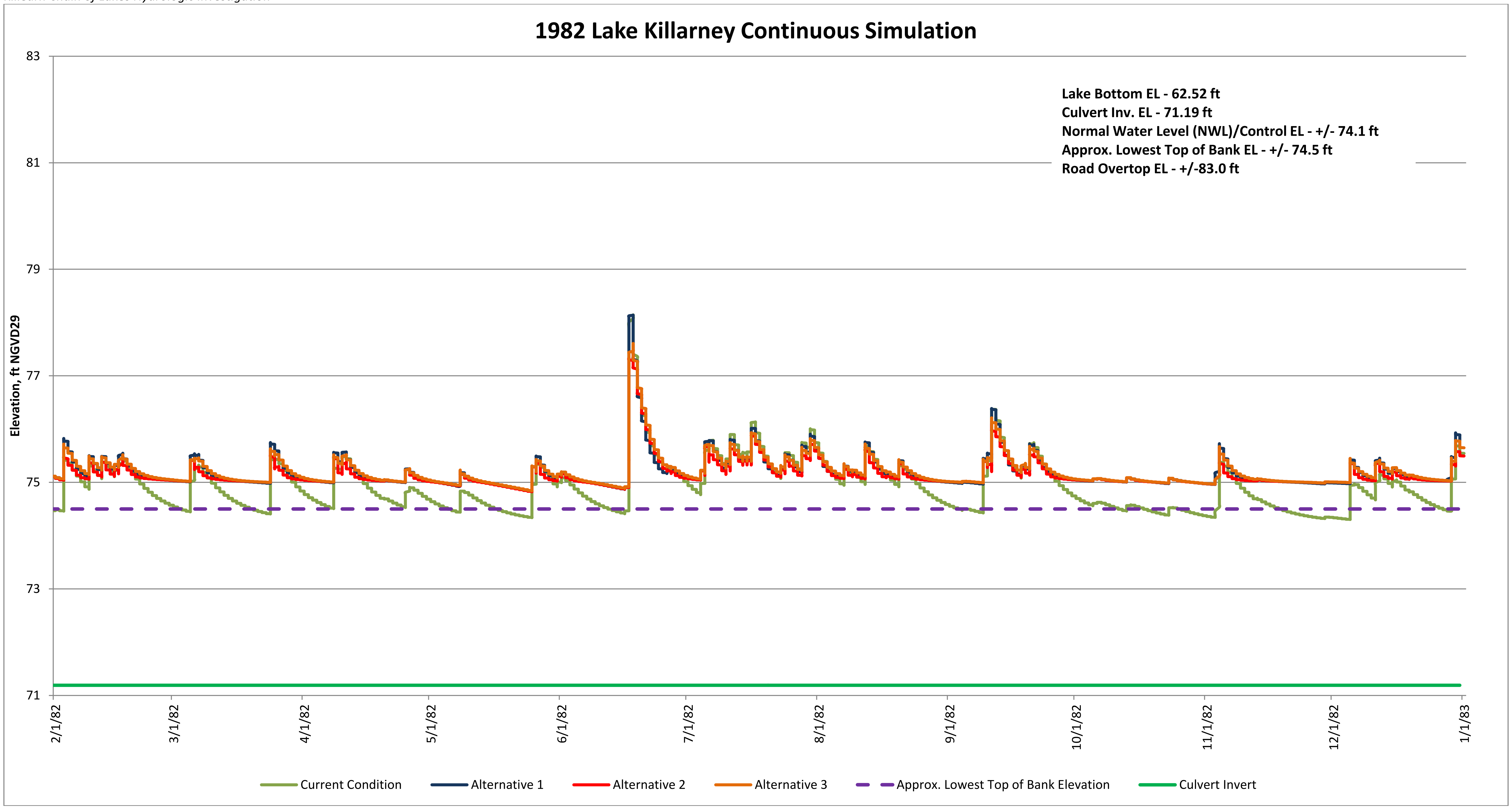


FIGURE 6A
Lake Kanturk Simulations using the FEMA KCOL Model for Historical and Current Conditions
Killearn Chain of Lakes Hydrologic Investigation

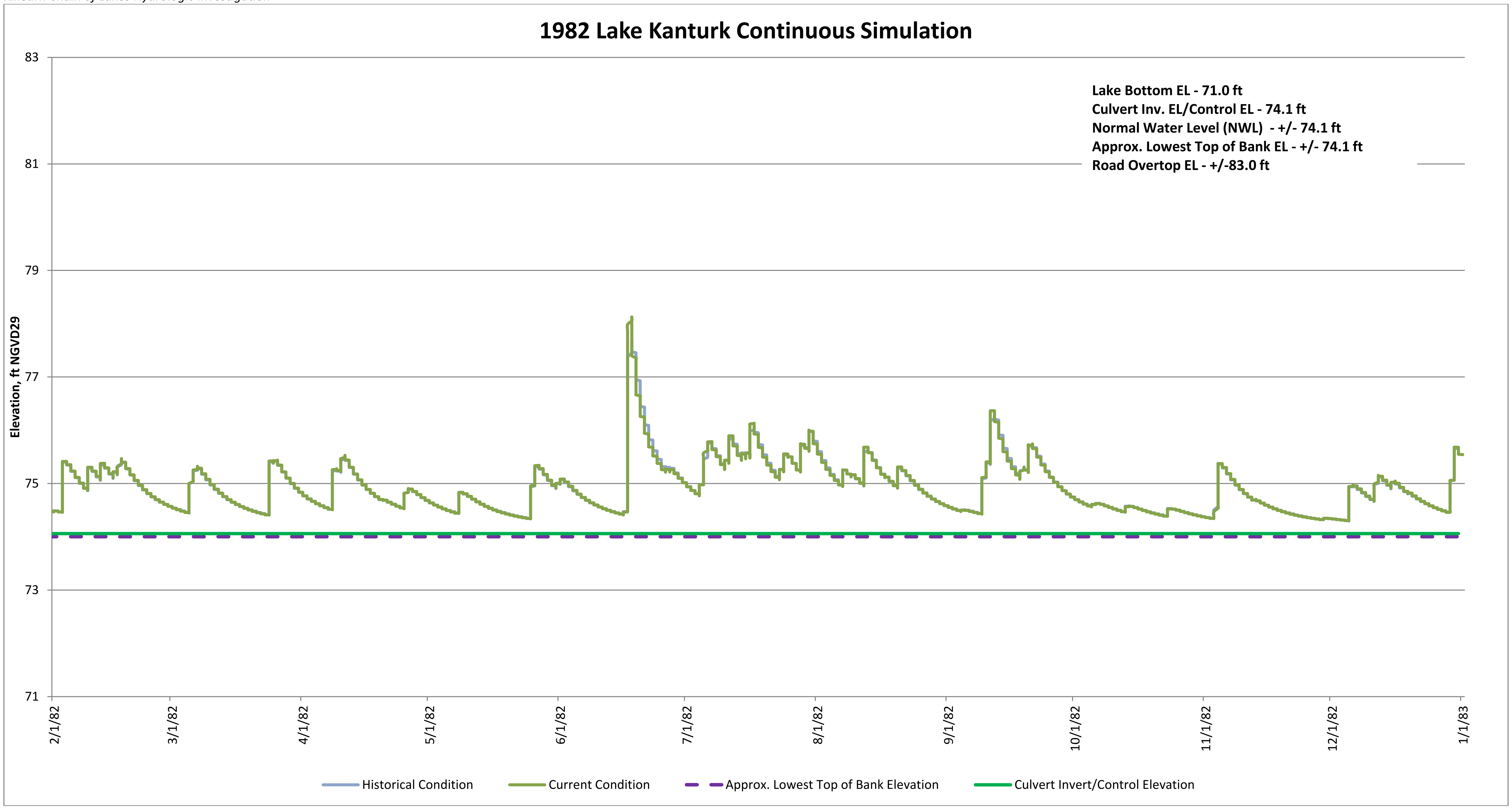
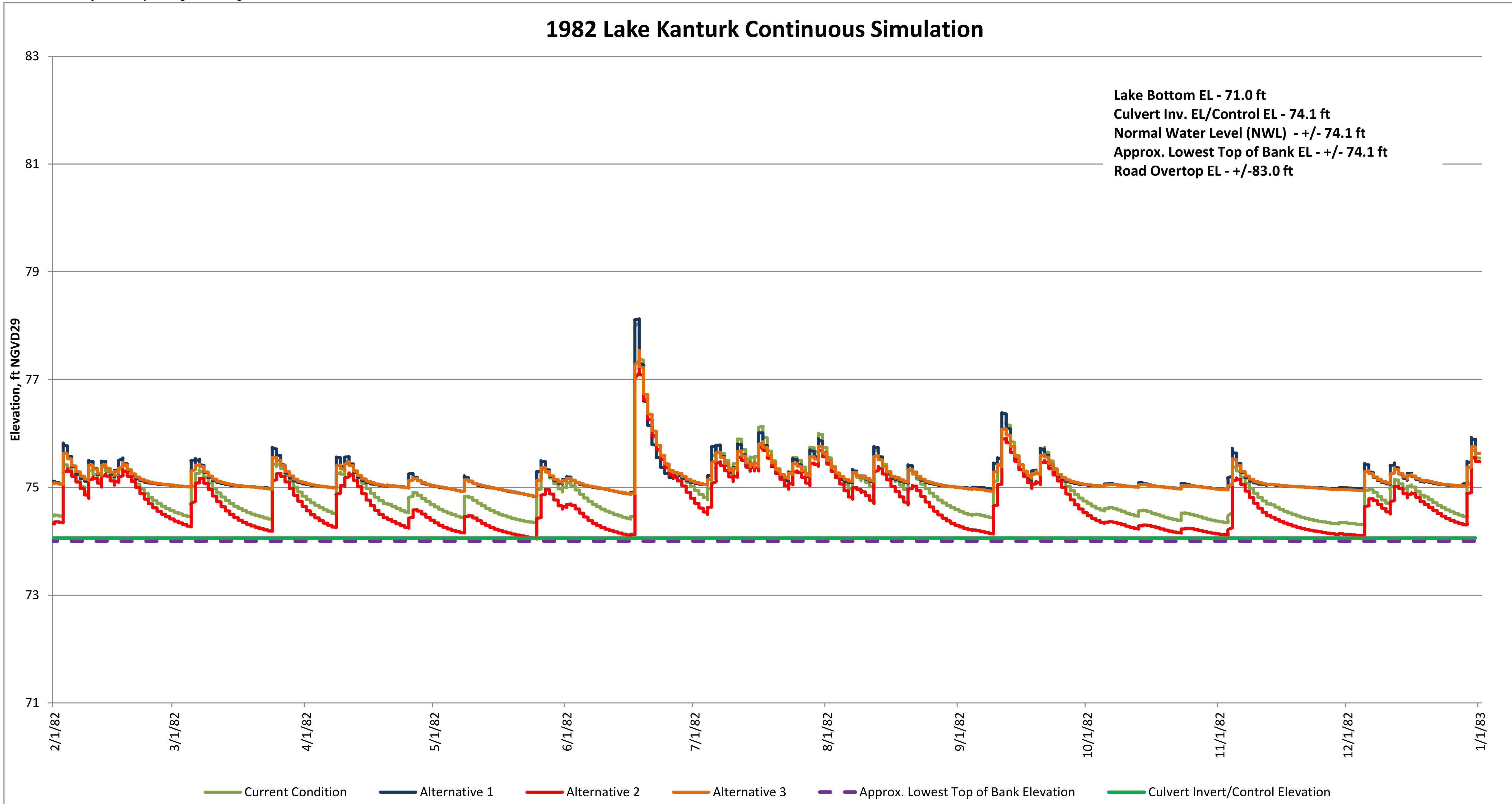


FIGURE 6B

Lake Kanturk Simulations using the FEMA KCOL Model for Current Condition and Proposed Alternatives

Killearn Chain of Lakes Hydrologic Investigation

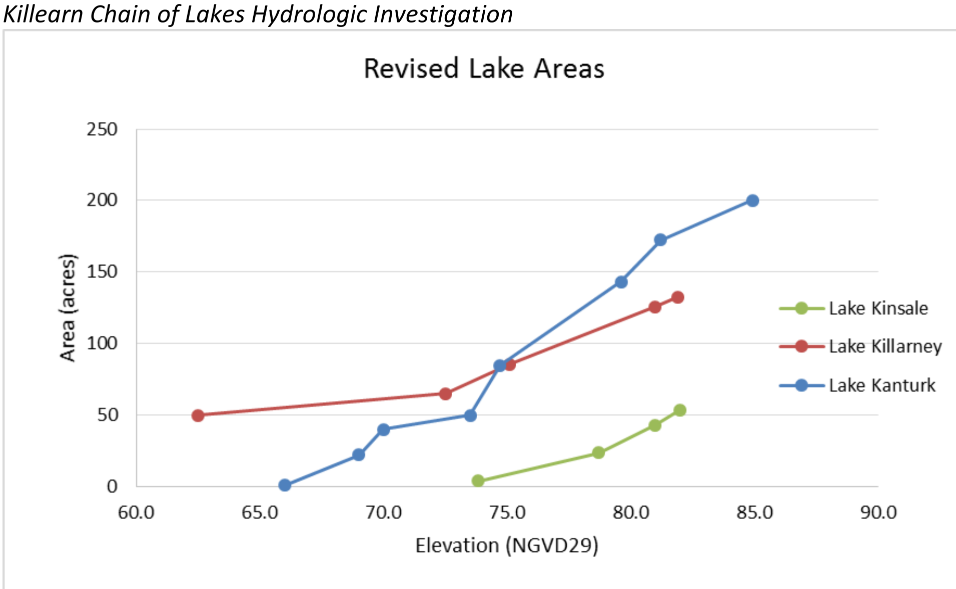


Using average or wet years to evaluate potential projects was not as useful as reviewing a very dry year. Aerial images readily available from Google Earth indicated that the lakes were very dry December 1999, May 2007, and January 2012. Furthermore, Lake Kanturk was often dry while some water was still in Lake Killarney's deep zone. Lake Kinsale was typically wetter (more area with water) than the other two lakes. Rainfall data for 2007 was available and used to examine water levels during a dry year. The dry period shown during 2007 is a USDA photograph dated May 7, 2007. Because the Google Earth elevation data available do not correspond to the imagery date, the water level during the survey is unknown. In addition to being dry, there were clusters of circular depressions in the bottom of Lake Kanturk which are characteristic of sinkhole activity. While there are no obvious open sinkholes, the low lake levels were assumed to be related to greater groundwater seepage. Furthermore, because Lake Kanturk was much lower than Lake Killarney during dry periods (about 4 feet lower), it is likely that Lake Kanturk seeps faster than the others.

Another issue observed from the Google Earth elevation data was that the ground elevations in the lakes were lower than those listed in the FEMA model. The newer elevation data were obtained by LiDAR, a laser-based remote sensing method. The laser does not reflect below the water surface, so the topographic data in the lakes are the surface levels or the ground at the time of the survey. For Google Earth to measure elevations below the apparent water level, the elevation of the lakes was depressed during that survey (dry season or year). In fact, Lake Kanturk was dry during the survey and its lowest elevation in Google Earth was 65. Lake Killarney still had water in its low spots at elevation 69. Therefore, the lake elevation versus area relationships in the computer model needed to be extended downward to capture low water levels observed in the 2007 aerial photos.

The elevations for Lake Killarney and Kanturk were extended downward by visually reviewing approximate areas on the aerials at the reported elevations in Google Earth. The revised chart of the elevation versus area is shown in Figure 7.

FIGURE 7
Expanded Lakes Area with Elevation
Killearn Chain of Lakes Hydrologic Investigation



Groundwater Model Changes

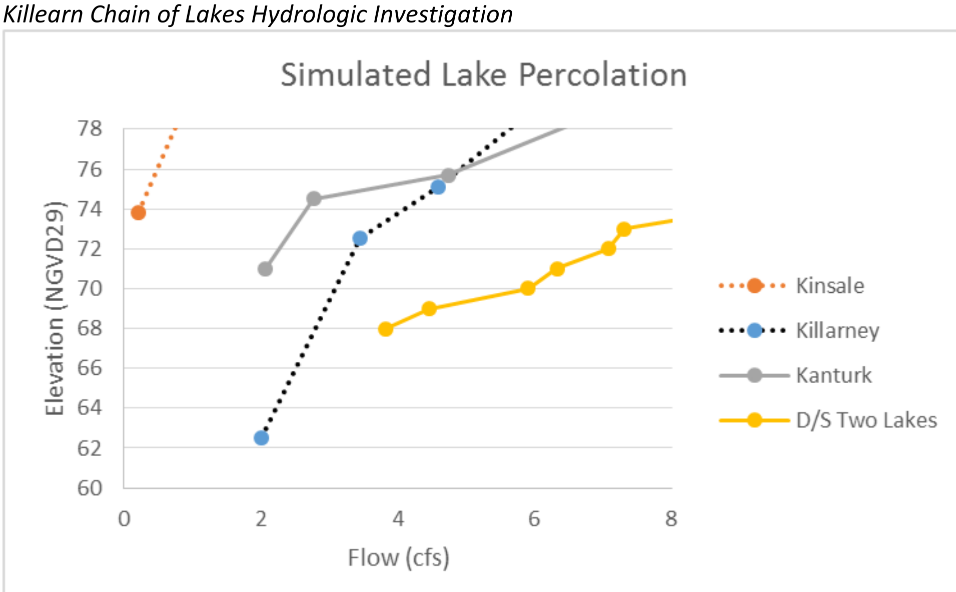
The FEMA KCOL model was modified to reflect the observed response in the lake levels by conducting some simulations with different infiltration rates. The infiltration rates were added to only the KCOL lakes by estimating a rating curve based on area and percolation rate. The percolation rate was adjusted slightly for depth to groundwater table which was assumed to be at elevation 30 feet. Table 8 provides the percolation rates used in the models.

A revised model was prepared, referred to as the KCOL groundwater model not because it simulates groundwater but because it accounts for percolation as well as other issues. A summary of the changes made to the FEMA KCOL model to reflect all of the changes described above follows:

- Simulated a dry year, 2007, and the average year 1982 to review the lake levels
- Added monthly ET to equal 49 in/yr
- Deepened the stage versus area curve for Lake Kanturk and Lake Killarney
- Selected a typical percolation rate of 0.5 inches per hour (in/hr) for Lake Kinsale and Killarney, and a higher rate of 0.7 in/hr for Lake Kanturk. Estimated the groundwater losses in cfs based on the stage versus area curve and the percolation rates described above. Added a rating curve link to the model from each KCOL lake to a dummy groundwater node to simulate percolation.

The percolation loss from the three lakes is significant. Figure 8 illustrates the losses included in the model. Because Lake Kinsale is small, its losses are relatively small. However, because the two downstream lakes are more closely interconnected above elevation 71 and they are larger, their combined groundwater loss was estimated to be high, about 4 to 5 cfs (about 3 mgd) AADF below elevation 70. ET losses are small in comparison (less than 1 cfs).

FIGURE 8
Simulated Percolation Losses to Approximately Duplicate Observed Dry Season Results
Killearn Chain of Lakes Hydrologic Investigation



Comparison of Historical Conditions versus Existing Conditions

The new box culverts were installed in the 1990s, and incidentally the supplemental groundwater pumping was ceased about the same time (maybe a few years apart). Although the actual groundwater pumping rates are unknown, supplemental water from two groundwater wells could approach the 3 mgd level. Consequently, the natural drawdown during dry seasons or years was not really experienced by the HOA while the older culverts were in place. The water levels from the 1970s until the 1990s were always supplemented; and even if the lake levels were low, the drawdown was not as rapid or low as they would have been without the extra groundwater. Without supplemental water, both lakes drawdown during the spring and late fall during dry years. Also, because the two lakes are interconnected (previously at elevation 72.7, now at 71.1) and they percolate at different rates, the rate of change of the water levels between the two lakes differs.

Figures 9 and 10 provide charts of the two downstream lakes based on the historical culverts and new box culverts for 1982 and 2007 conditions. From these charts it appears that below elevation 72, there would be a 7- to 10-day faster recession in Lake Killarney with the box culverts when compared to the old culverts. Also, the levels in Lake Killarney may reach about 0.75 foot lower in the average rainfall year of 1982; however, during the dry year the difference in elevation is less than this. For Lake Kanturk there is a different response. The control elevation at Lake Kanturk remained nearly the same between historical and existing conditions. Because there is more contributing area to this lake, the lower interconnection between the two lakes box culverts actually helps keep Lake Kanturk levels a little higher longer (about 7-days) than during historical conditions. Once below the interconnection level, Lake Kanturk would recede at the same pace between the two conditions until it went dry during the 2007 simulation; and that occurred both in the spring and fall.

From these simulations it appears that seepage from Lake Kanturk has the potential to reduce the water levels in Lake Killarney somewhat faster than prior to the box culvert installation. The rate of change and magnitude of water level differences is small, but could be noticeable in the shallow Lake Killarney.

Refined Alternatives when Including Groundwater Loss

With the redefined KCOL groundwater model, the type of projects that could be implemented changes from one of simply holding back more water by weirs to how to overcome large losses in the system. The previous FEMA model and results would be indicative of the performance of the lakes if they were totally sealed. A lake sealing project of this scale, about 125 acres, would be difficult to construct and permit. However, if the sealing efforts were undertaken for the most critical location in Lake Kanturk, a lake that often goes dry, it may be more permittable and of reasonable scale.

Furthermore, based on past performance, supplemental water would also overcome the groundwater percolation rates, although at a cost of operating and maintaining the pumps. This option is likely to be difficult to permit given the sensitivity of water use for beneficial purposes, but given that most of the water percolates right back to the local groundwater and the net loss of groundwater to ET is low (about 0.5 mgd), this source may be feasible. There is also an option to obtain supplemental water from reclaimed wastewater. A scalping plant is a small facility that can treat wastewater locally for reclaim use, depositing its sludge and residuals back into the main sewer system. Given the nature of the lakes, though, this scalping plant would have to remove nutrients which would greatly increase the cost and footprint of a plant site. A small scalping plant could reach approximately $10 million dollars, plus the land (0.5 acres to 1 acre, depending on the size), project design and development, and the long term operations and maintenance costs. While a scalping plant is unlikely feasible, a small supplemental water supply was evaluated without specifying the source of water.

The revised scenarios are listed in Table 8. This list summarizes potential conceptual projects and do not necessarily mean that they are actually feasible. However, they are technically feasible. Sealing Lake Kanturk may not be easy, but a layer of bentonite clay (or just a heavy local clay) could be imported and spread across either part of the lake, or over the whole lake. Adding supplemental water to Lake Killarney was examined, but as long as seepage is higher at Lake Kanturk and the two lakes are interconnected at elevation 71.1, there was less impact than putting the supplemental water directly into Lake Kanturk. However, if a weir is constructed between the two downstream lakes then the drawdown in Lake Killarney would be slowed and sometimes reduced. Only one high elevation was simulated here, but if this option is considered for future implementation, additional refinement would be needed. No specific projects are identified for Lake Kinsale, because the previous weir seems to improve water levels there and the need for change is greater in the other two lakes.

FIGURE 9
Historical and Current Conditions Simulation Lake Killarney Results with KCOL Groundwater Model
Killearn Chain of Lakes Hydrologic Investigation

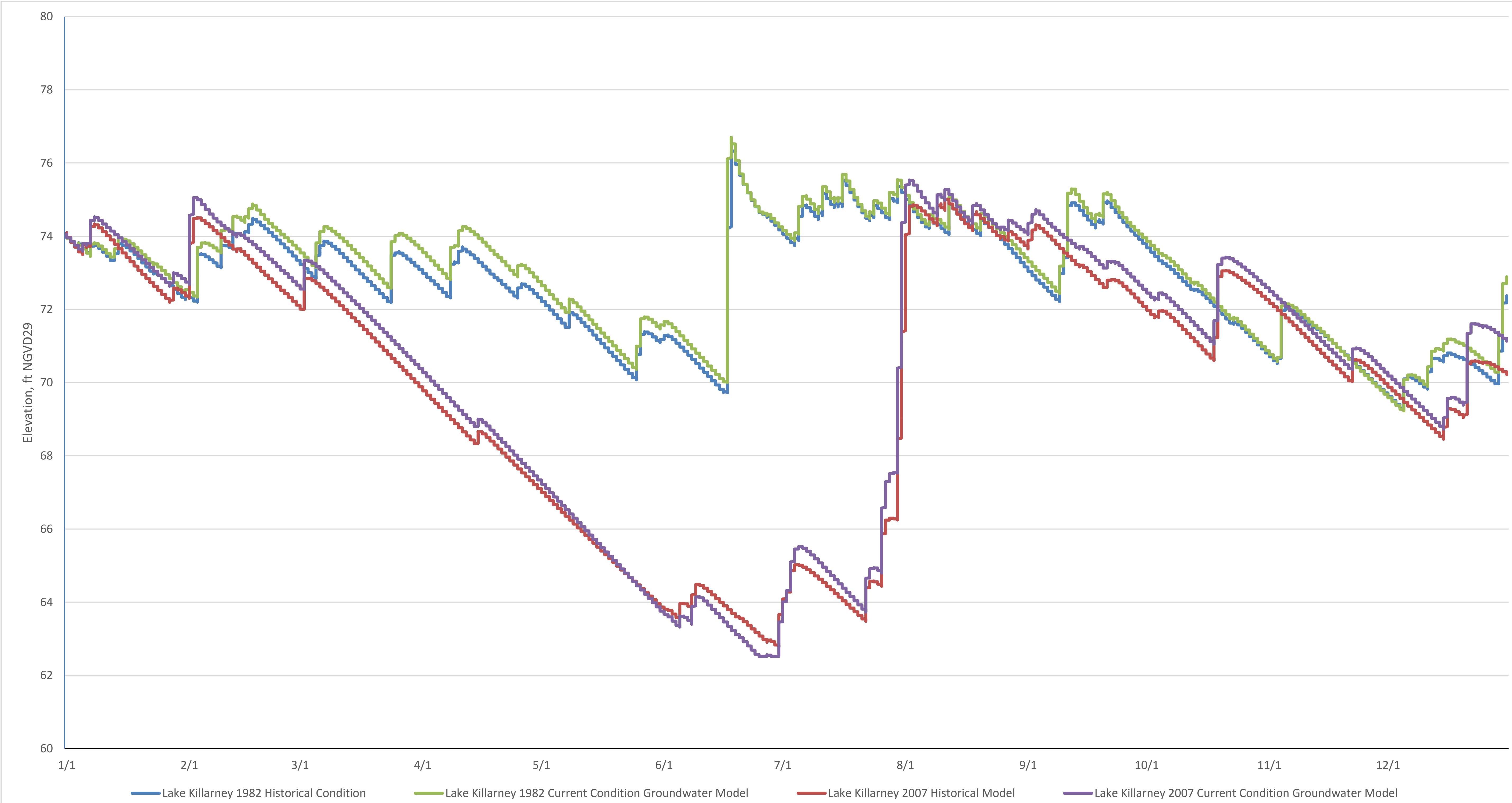


FIGURE 10
Historical and Current Conditions Simulation Lake Kanturk Results with KCOL Groundwater Model
Killearn Chain of Lakes Hydrologic Investigation

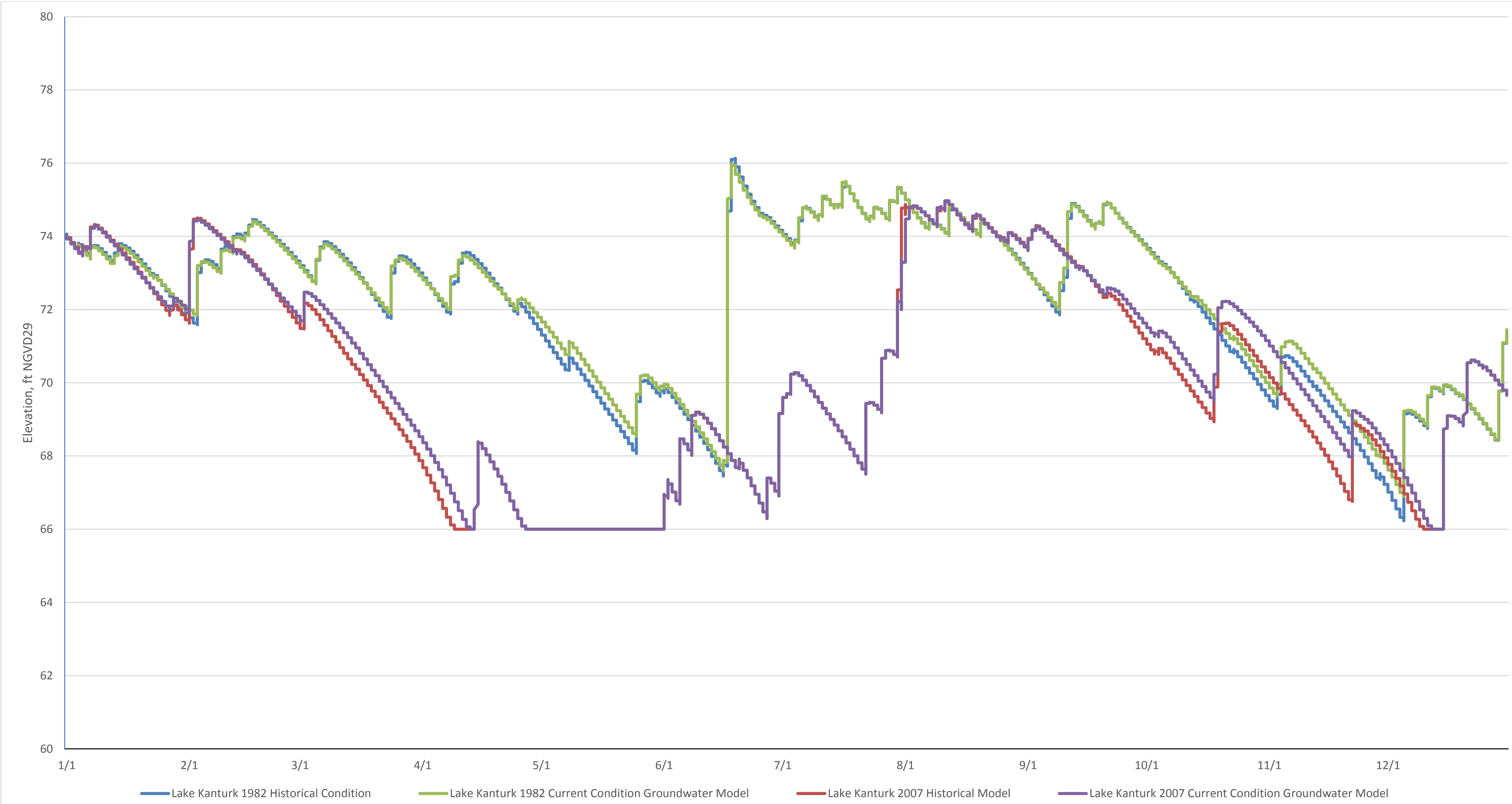


TABLE 8
Redefined Investigation Alternatives of Possible Projects that will Alter Lake Levels in KCOL
Killearn Chain of Lakes Hydrologic Investigation

Alternative	Description	XPSWMM File Reference Name
0.	Original Baseline. No infiltration and small ET loss, FEMA model	Base
1.	Add infiltration to the KCOL lakes and higher ET, KCOL groundwater model	Scen_GW
2.	Seal Lake Kanturk, entire bottom	Scen_GW_noK3
3.	Seal only the lower levels of Lake Kanturk, to about elevation 70	ScenGW_0.5K3
4.	Raise the control elevation of Lake Killarney to a higher elevation (up to EL 75)	ScenGW_K2w
5.	Add 1 mgd of supplemental water into Lake Killarney	ScenGW_RecK2

Potential Project Descriptions and Costs

The revised scenarios listed above represent only a few types of projects: sealing the lake, weir, or groundwater use. While the rationale for choosing these projects were discussed above, additional details are provided in this section. The preliminary nature of these alternatives makes the accuracy of the cost opinions in the -30 to +50 percent range. The total capital cost would be higher to include the design and other potential fees (permitting, right-of-ways, and so forth, as needed).

Sealing Lake Kanturk

The logistics of sealing Lake Kanturk would likely be a challenge. If not done during a drought, the lake would need to be dewatered to provide construction access to its bottom. Also, large volumes of stormwater runoff might need to be controlled during the project. The lake bottom could be sealed by spreading and compacting clayey soil about 1.5 feet deep to greatly reduce the seepage rate. Sealing Lake Killarney may be feasible also, but it has a wetland habitat that is more evident than in Lake Kanturk, primarily because Kanturk periodically dries up completely, while the deeper zones of Lake Killarney still retain water. Because of the apparent circular patterns seen in the bottom of Lake Kanturk, the City should try to gather more subsurface data related to groundwater conduits. Sealing the lake(s) may be more difficult with the presence of vertical conduits which may affect the structural integrity of the soil causing a future loss of material.

Some clays tend to swell when wet (bentonite) and are used to seal ponds and lagoons. This type of clay can be expensive if not locally available. However, there should be clay available in the Tallahassee region that could be used to reduce seepage. A search for suitable source material is required to be able to accurately predict the hauling costs. However, an opinion of the potential cost was prepared for comparison purposes.

Figure 11 illustrates the lower half of the lake below elevation 70 which was used for this evaluation. Costs for this alternative were developed using RSMeans cost data (RSMeans, 2012). Table 9 provides the construction cost opinion for sealing about half of Lake Kanturk (24.3 acres). Sealing the entire lake would be about double the cost (50 acres). The cost of this alternative is highly dependent on the distance that the material is hauled.

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FIGURE 11
Approximate Limit of Sealing the Lower Portions of Lake Kanturk
Killearn Chain of Lakes Hydrologic Investigation

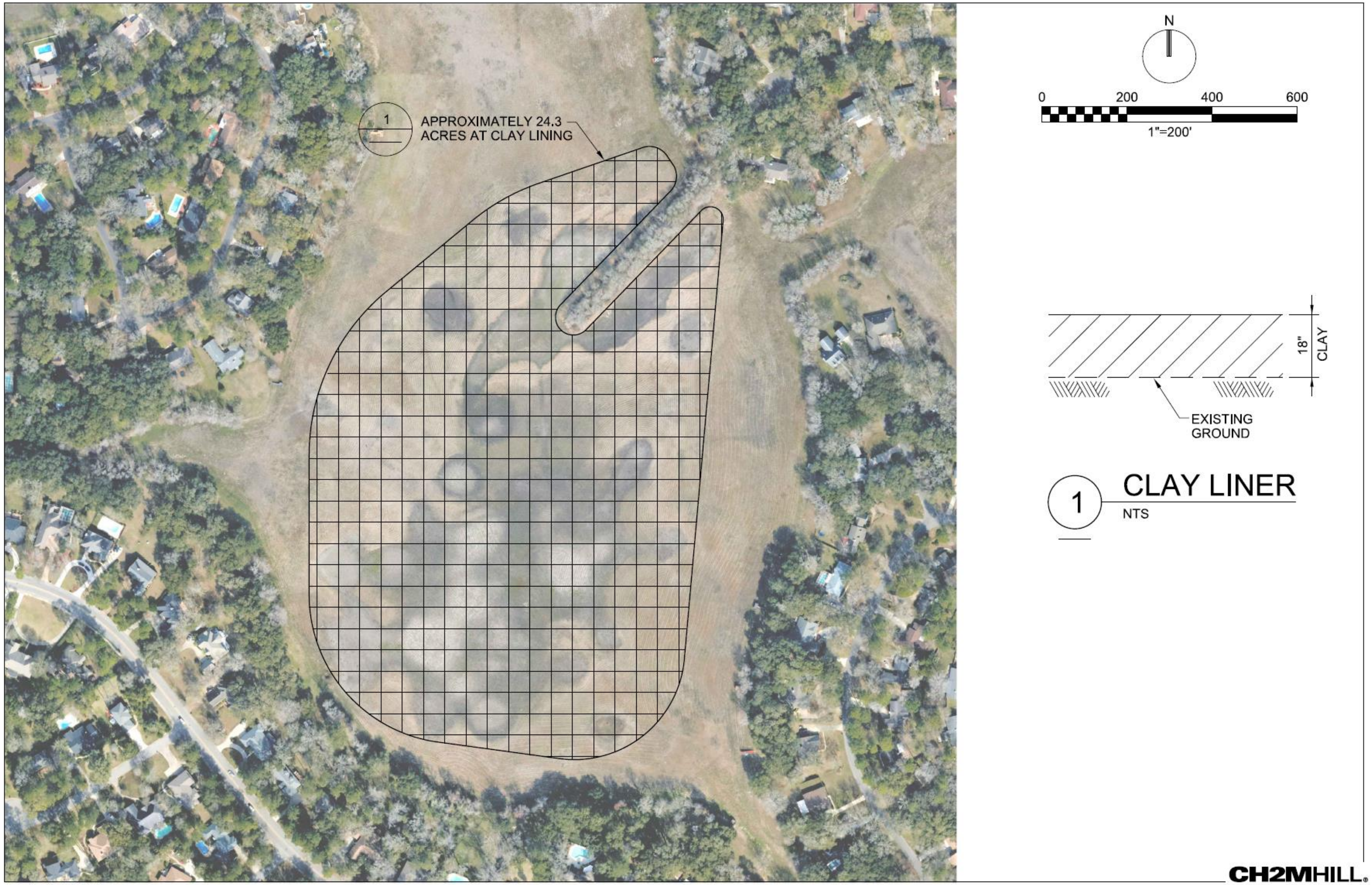

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TABLE 9
Cost Opinion for Sealing the Lower Portions of Lake Kanturk
Killearn Chain of Lakes Hydrologic Investigation

Item	Description	Unit Cost	Quantity	Cost
31 05 13.10, 0700 & 0900	Borrow and spread screened loam, 5 mile haul	$49/CY	58,806 CY	$2,881,494
31 23 23.23, 5620	Compaction, sheepsfoot roller, 6” lifts, 3 passes	$1.15/CY	58,806 CY	$67,627
	Subtotal			$2,949,121
	Overhead	10%		$294,912
	Contingency	20%		$589,824
	Total			**$3,833,857**

Weir to Separate Killarney from Kanturk

A sheet pile weir with a concrete cap can be installed between Lake Killarney and Kanturk. There is an earthen channel about 40-feet wide that separates the main body of Lake Killarney and the downstream box culvert. The weir could be installed anywhere along this channel, right up to near the box culvert. The control elevation studied here was set at elevation 75, but that may need to be revised if it is determined that the peak elevation during a storm changes too much to be acceptable to the FEMA NFIP coordinator. This could be overcome by stretching the length of the weir by changing the shape or angling across the channel so the weir crest length is longer. An evaluation was conducted to determine a weir length that would produce similar capacity to the double box culvert. A 60-feet wide weir crest would match the box culverts’ capacity, but the 40-feet wide channel may be limiting enough such that a shorter weir could be just as effective without additional impact. The most likely location for installation is assumed to be near the box culverts as shown on the schematic in Figure 12.

Table 10 provides the construction cost opinion of the weir with riprap stabilization downstream of it. Costs for this alternative were developed using Florida Department of Transportation average pay item unit costs for 2012.

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FIGURE 12
Schematic Drawing of a Conceptual Weir to Separate Lake Killarney from Lake Kanturk
Killearn Chain of Lakes Hydrologic Investigation

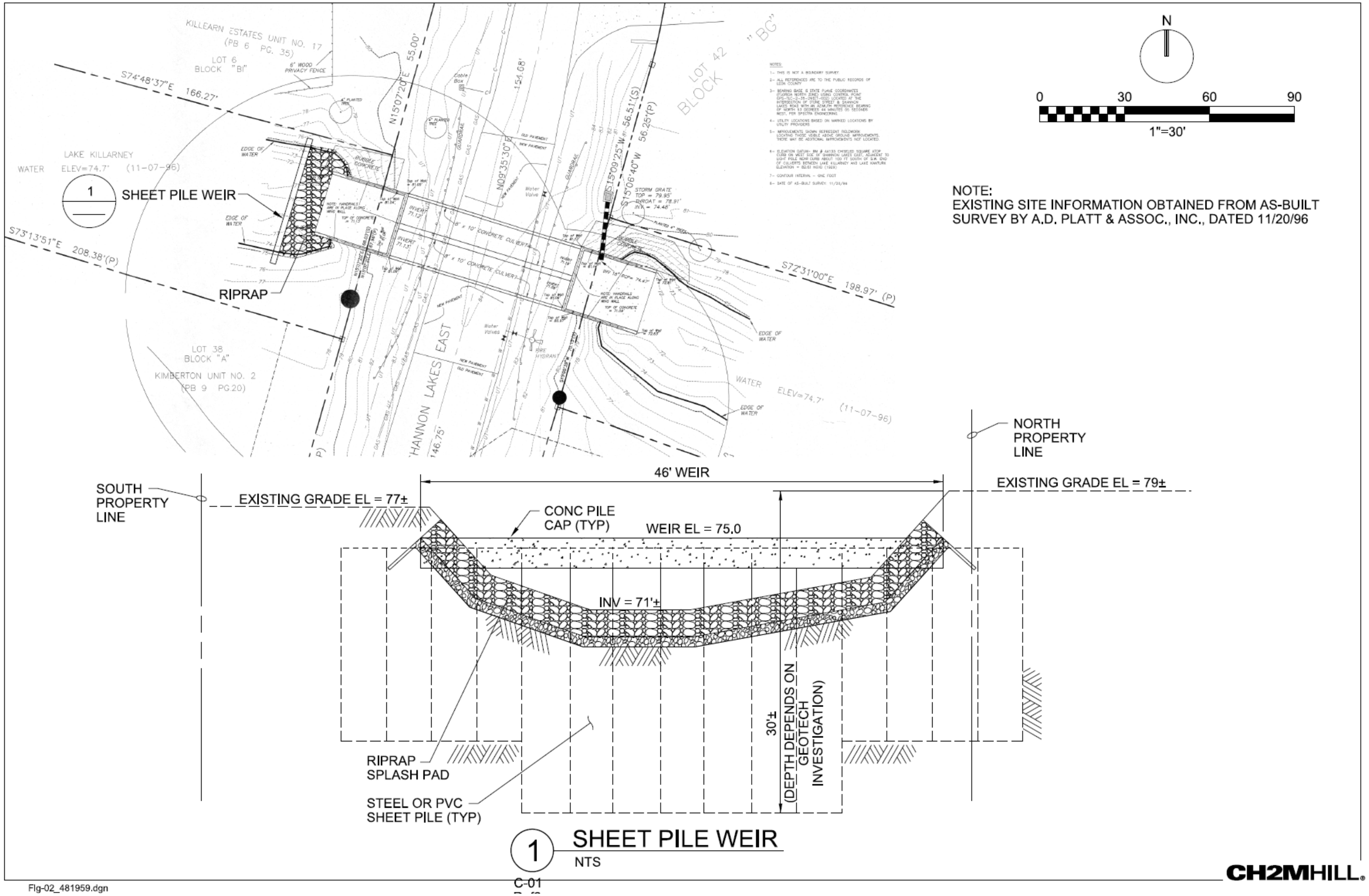

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TABLE 10
Cost Opinion for Separating Lake Killaney from Lake Kanturk
Killearn Chain of Lakes Hydrologic Investigation

Item	Description	Unit Cost	Quantity	Cost
0455133 3	Sheet Piling Steel, F&I Permanent	$43.49/SF	1,380 SF	$60,016
0530 3 4	Riprap, Rubble, F&I, Ditch Lining	$90.41/TN	41.4 TN	$3,743
	Subtotal			$63,759
	Overhead	10%		$6,376
	Contingency	20%		$12,752
	Total			**$82,887**

F&I means furnish and install

Supplemental Water

As discussed previously, a supplemental water supply was deemed technically feasible, but permitting a new groundwater well may be difficult. It is assumed that despite this difficulty, restarting the wells would be more practical than building a new wastewater treatment plant just for scalping reclaimed water. However, if additional customers for reclaimed water could be identified in the neighborhood (golf course and so forth), then the scalping plant may be an option.

KCOL is technically in the Wakulla Springs springshed although not in its most directly connected karst zone south of the Cody Scarp (http://www.floridasprings.org/expedition/wakulla/protectingwakulla/springshedmap/). Information about the old wells is limited, but it is assumed that the previous supplemental wells are relatively shallow and their pumping systems would need to be replaced. However, it may be possible that one or both of the wells may be rehabilitated for future use. Probably only one of the previous wells would be used, so the supplemental pumping rate would be about half of its historical use. One old pumping station is located close to Lake Kinsale's outlet and it could easily be piped to pump to the outlet culvert. For this study, a value of 1 mgd was assumed available, but it could be more depending on the condition of the wells. In addition to a field investigation on using the old wells, permitting a groundwater withdrawal will require groundwater modeling, possible test and/or observation wells, and a long term monitoring program once operational.

Costs for this alternative were developed using RSMeans cost data (RSMeans, 2012) and the professional opinions of CH2M HILL hydrogeologists who are familiar with this type of work. Table 11 provides the cost opinion for minor well rehabilitation and a new pump for both wells, but the success of this option needs further testing and regulatory review.

TABLE 11
Cost Opinion for Rehabilitating Two Existing Wells
Killearn Chain of Lakes Hydrologic Investigation

Item	Description	Unit Cost	Quantity	Cost
33 21 13.10, 3100	Pump, 6” submersible, 30 H.P.	$12,000/EA	2 EA	$24,000
	Subtotal			$24,000
	Overhead	10%		$2,400
	Contingency	20%		$4,800
	Total			**$31,200**

Summary Discussion of Results

The results are illustrated in Figures 13 through 16 for 1982 and 2007 for both Lake Killarney and Kanturk, respectively. Design storm simulation results are presented in Attachment B. One has to study the annual plots to see the differences between the scenarios, but the following general observations can summarize the effects of the potential projects.

- Adding the weir between Lake Killarney and Kanturk with a crest at elevation 75 will help raise the water levels in Lake Killarney by 1 to 2 feet during the average year’s dry season. The lake will still fluctuate during the year and during dry years, but not by as much. This change alone almost matches the supplemental water scenario. The final elevation of the weir crest is subject to further refinement.
- Adding 1 mgd of supplemental water to Lake Kanturk would raise Lake Killarney by about 2 feet during the dry season and maybe more during a dry year.
- Sealing Lake Kanturk can have as much impact as the supplemental water to Lake Killarney. The biggest difference in this scenario is that both lakes will retain water better during dry weather. There is a difference in impact whether the lake is fully or half sealed, as follows:
  - Lake Killarney will be up to 4-feet higher during the 1982 dry season if Lake Kanturk is fully lined.
  - Lake Killarney will be up to 1-foot higher during the 1982 dry season if Lake Kanturk if half lined.
  - Lake Kanturk will be about 4- to 5-feet deeper during the 1982 dry season, depending if it is half or fully lined, respectively.

Regardless of the scenario evaluated, all lakes may go dry or near dry for some portions of year, especially when there is a low rainfall year like during 2007.

From these results, the City may choose to conduct further field studies to verify or quantify the conditions inferred from this desktop investigation. Areas for additional data gathering would include:

- The seepage rates could be more closely calibrated using observed water level data. This would be most helpful when the water level in Lake Killarney and Kanturk is below elevation 71. During this study, the City sought to obtain these data, but it has been too wet lately to provide a long-term drawdown curve. Other lake levels in the region were reviewed too, but they were considered too far away or not representative.
- Subsurface investigation of potential conduits (pre-sinkholes) using either sonic or ground penetrating radar (if dry). While Lake Kanturk was the focus of this study, both lakes may be studied if there is an economy of scale.

- Gather more information about wells around the lakes in addition to the historical documents and recent inspection documents from the water management district. If this option is chosen to be pursued further, then the City and HOA would need a memorandum of understanding to clearly delineate responsibilities during permitting, construction, and operations.
- The weir option would be a cost-effective project for Lake Killarney. The City should review its rights-of-way and refine the conceptual design. Talks with the NFIP department and water management district should be held, and then a planned permit process should be identified prior to design.
- The KCOL also have some water quality issues related to nutrients. Any synergy in combing objectives of water quantity and quality should be identified as soon as practical regardless of any project that may occur in these lakes.
- If sealing the lakes is an option, then like for the weir project, permitting process needs to be identified. Then potential sources of clay material should be identified and tested for suitability.

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FIGURE 13
Simulated 1982 Water Levels in Lake Killarney for Selected Conceptual Projects
Killearn Chain of Lakes Hydrologic Investigation

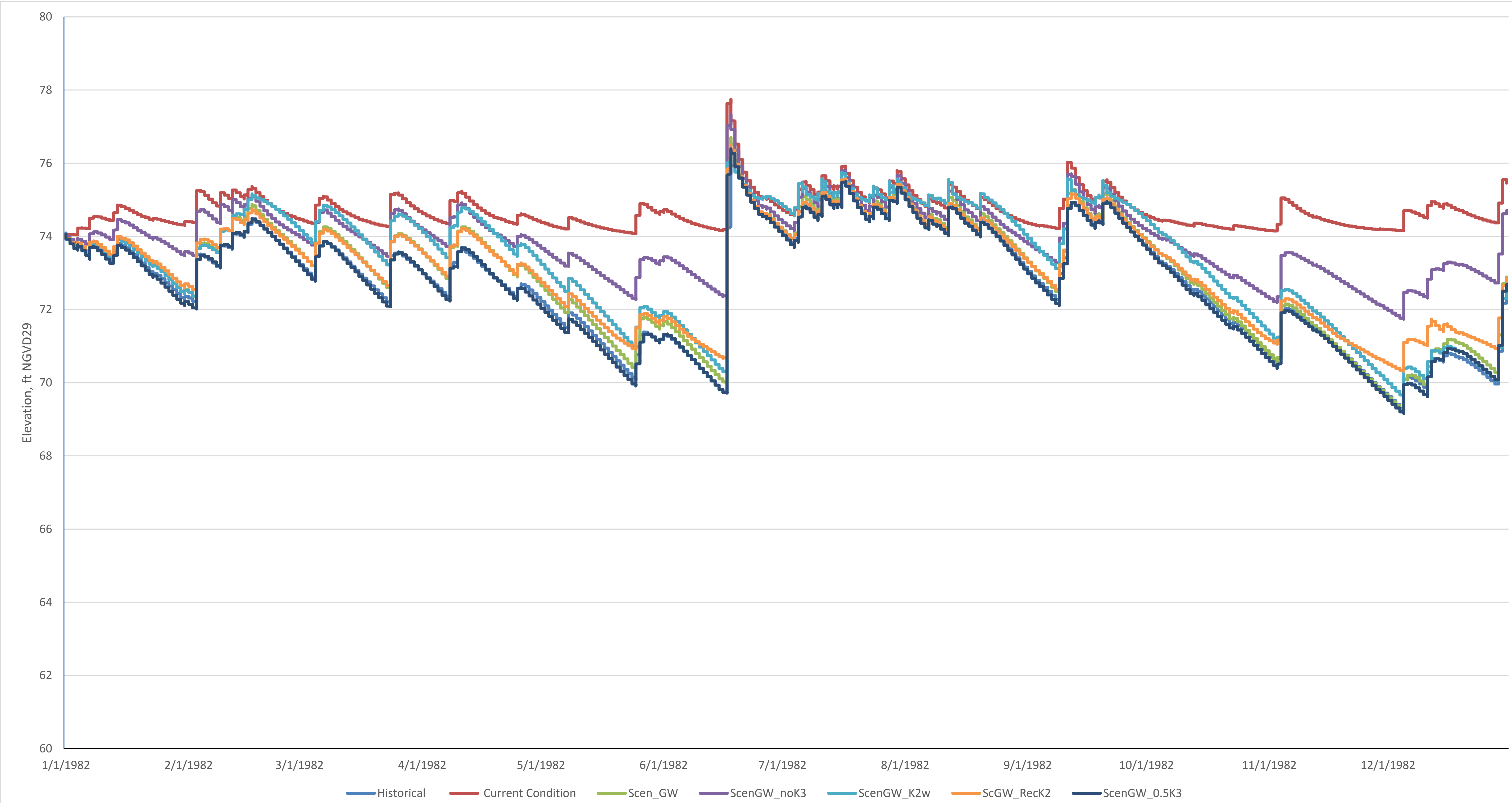


FIGURE 14
Simulated 2007 Water Levels in Lake Killarney for Selected Conceptual Projects
Killearn Chain of Lakes Hydrologic Investigation

FIGURE 15
Simulated 1982 Water Levels in Lake Kanturk for Selected Conceptual Projects
Killearn Chain of Lakes Hydrologic Investigation

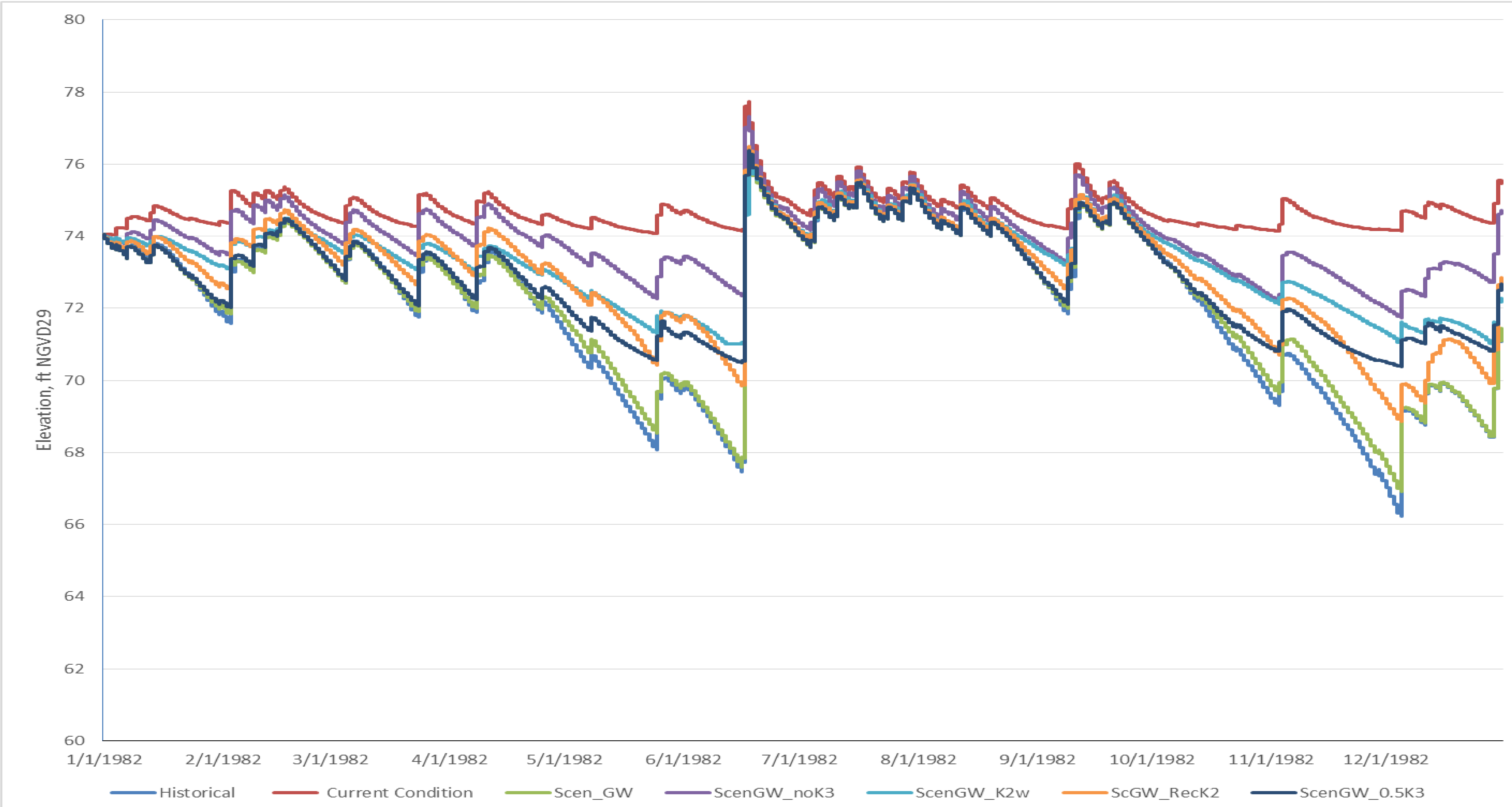
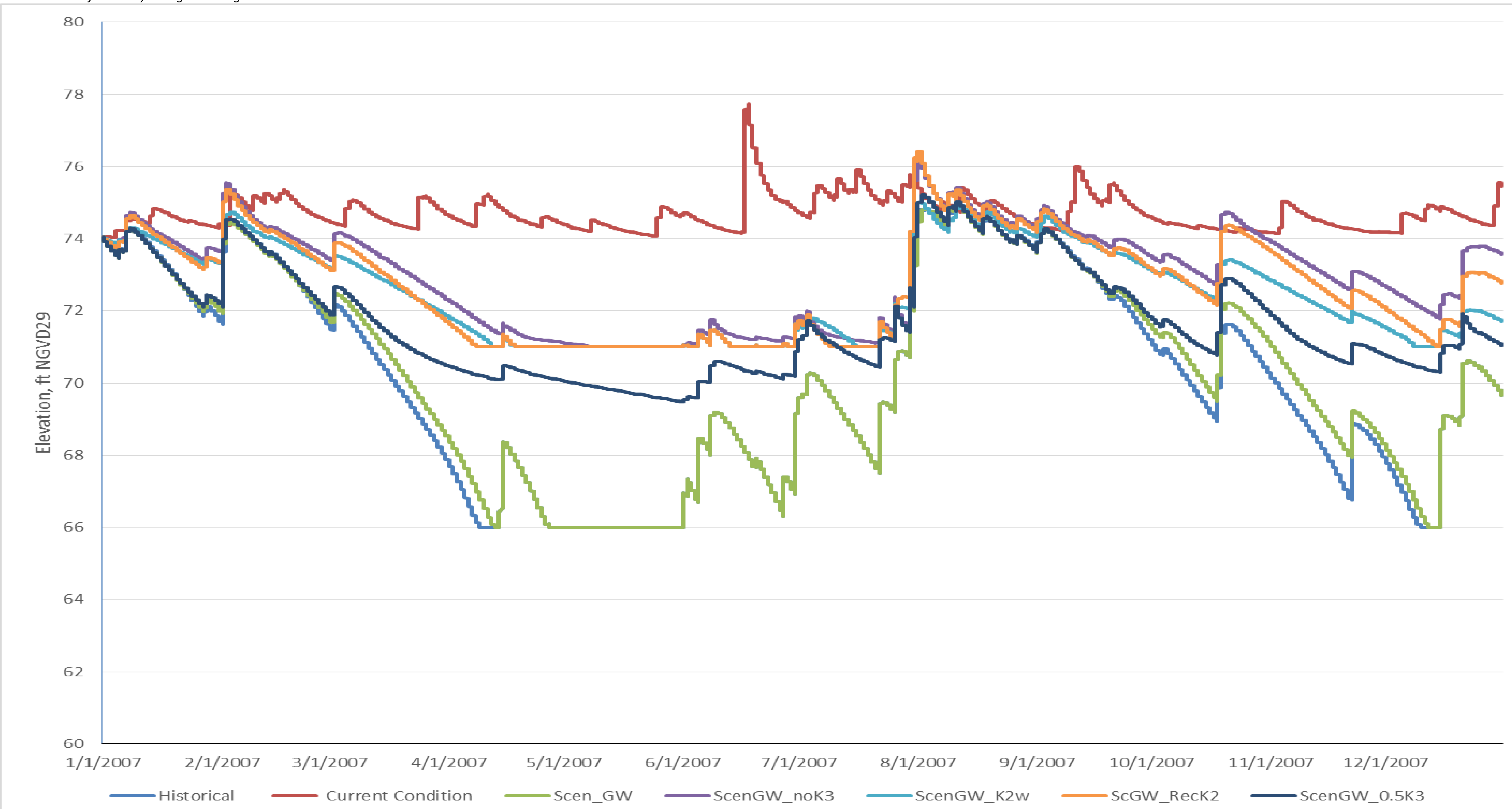


Figure 16
Simulated 2007 Water Levels in Lake Kanturk for Selected Conceptual Projects
Killearn Chain of Lakes Hydrologic Investigation



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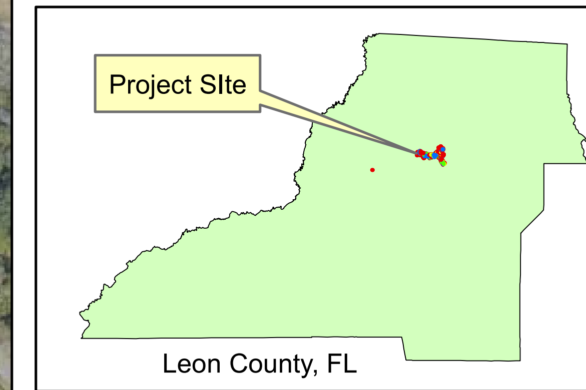
Spectra Engineering & Research, Inc. 1994b. Existing Conditions Survey of the Shannon Lakes Drive East Culvert. Prepared for Post, Buckley, Schuh & Jernigan. Inc. September 28, 1994.

ATTACHMENT A

Contour Maps of KCOL Lakeside



LEGEND

2-ft Contours, ft

- 74
- 76
- 78
- 80

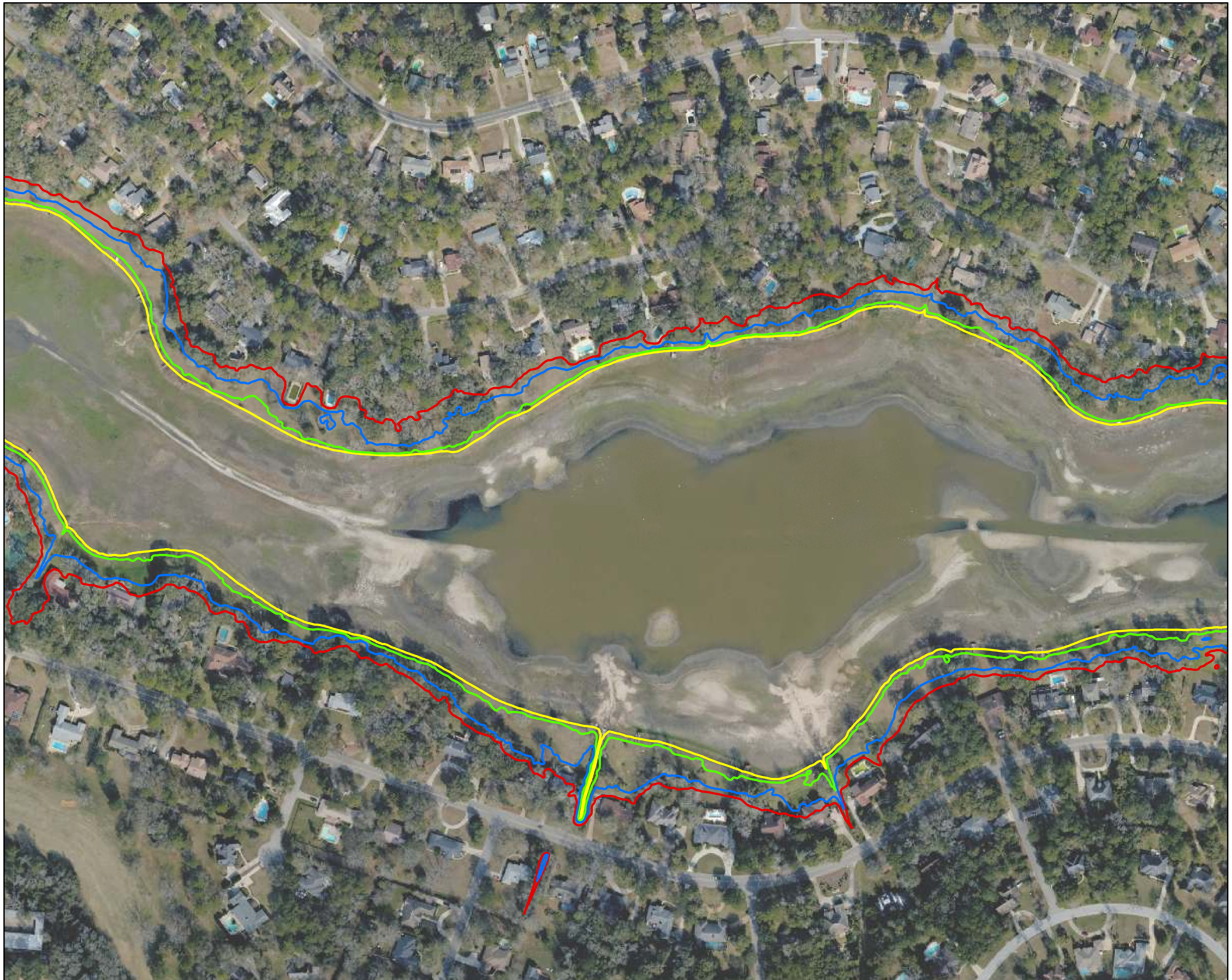
Source
Aerial: LABINS, 2012
2-ft Countour: City of Tallahassee, 2013

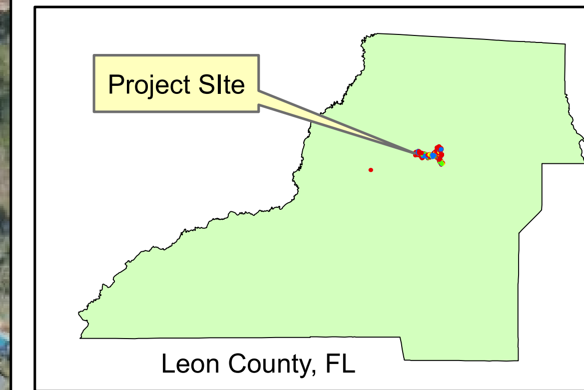
N

0 25 50 100
Feet

FIGURE A-1
2-ft Countour Map
Killearn Chain of Lakes Hydrologic Study
Leon County, FL

CH2MHILL





LEGEND

2-ft Contours, ft

- 74
- 76
- 78
- 80

Source
Aerial: LABINS, 2012
2-ft Countour: City of Tallahassee, 2013

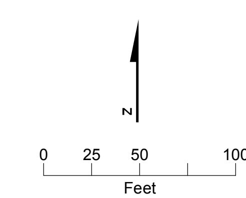
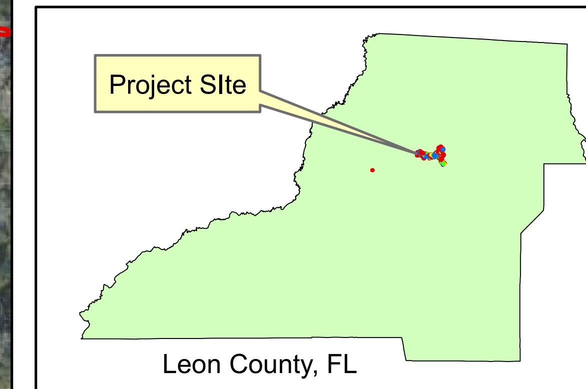


FIGURE A-2

2-ft Countour Map

Killearn Chain of Lakes Hydrologic Study
Leon County, FL

CH2MHILL



LEGEND

2-ft Contours, ft

- 74
- 76
- 78
- 80

Source
Aerial: LABINS, 2012
2-ft Countour: City of Tallahassee, 2013

N

0 25 50 100
Feet

FIGURE A-3
2-ft Countour Map
Killearn Chain of Lakes Hydrologic Study
Leon County, FL

CH2MHILL

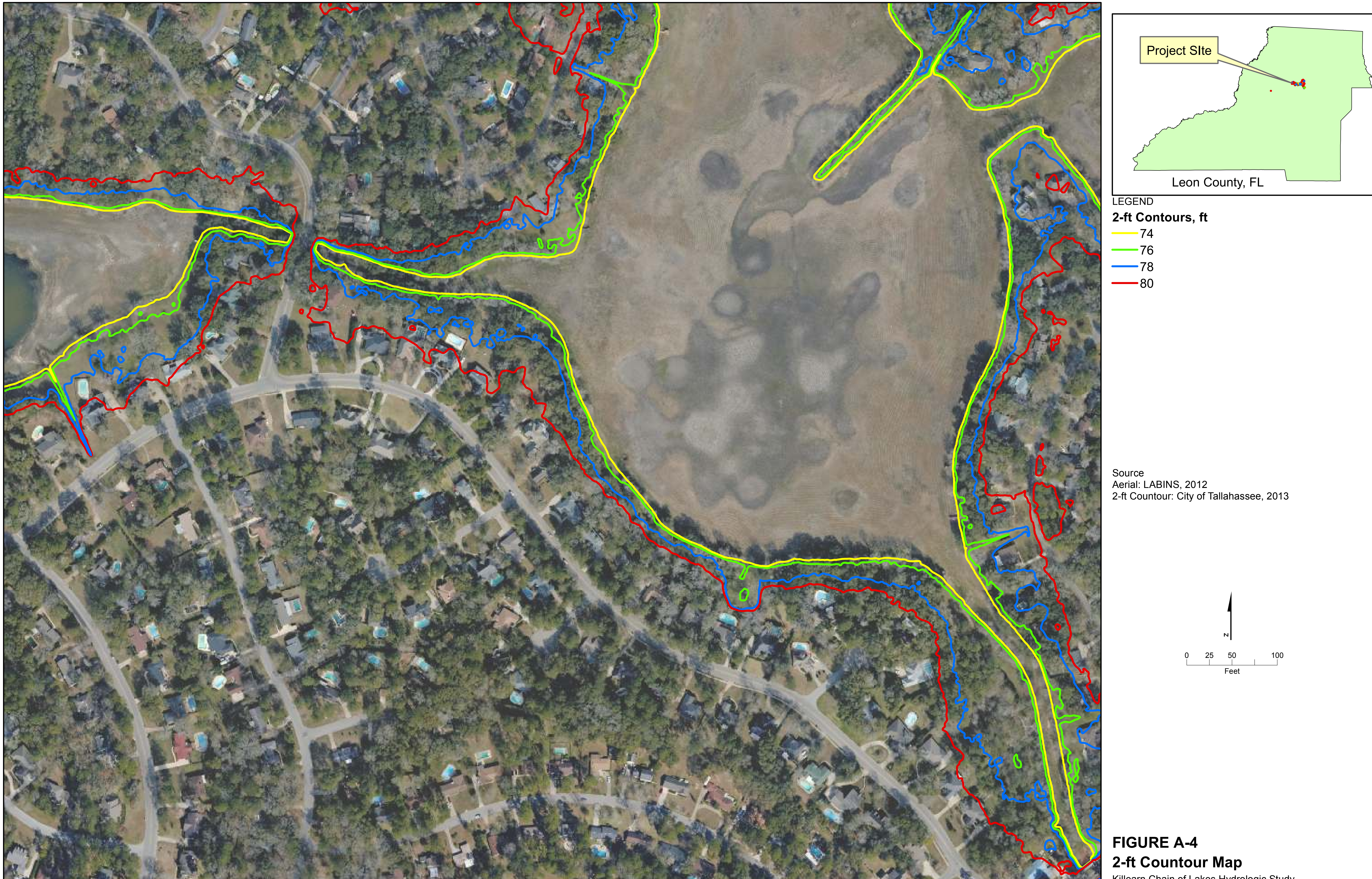


FIGURE A-4

2-ft Countour Map

Killearn Chain of Lakes Hydrologic Study

Leon County, FL

CH2MHILL

ATTACHMENT B

Summary of Design Storm Simulation Results

TABLE B1

Summary of 8-hour Design Storm Simulation for Scenario 0, Original Baseline with FEMA Model

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.83	77.77	77.76
10-yr 8-hr	6.2	78.52	78.43	78.41
25-yr 8-hr	7.4	79.67	79.52	79.45
100-yr 8-hr	8.9	81.11	80.90	80.76

Please refer to Table 8 for Scenario description

TABLE B2

Summary of 8-hour Design Storm Simulation for Scenario 1, New Baseline with Groundwater Seepage and Higher Evapotranspiration

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.76	77.69	77.68
10-yr 8-hr	6.2	78.45	78.37	78.35
25-yr 8-hr	7.4	79.60	79.45	79.38
100-yr 8-hr	8.9	81.04	80.82	80.69

Please refer to Table 8 for Scenario description

TABLE B3

Summary of 8-hour Design Storm Simulation for Scenario 2, Seal All of Kanturk

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.81	77.74	77.73
10-yr 8-hr	6.2	78.50	78.41	78.39
25-yr 8-hr	7.4	79.65	79.50	79.43
100-yr 8-hr	8.9	81.09	80.88	80.74

Please refer to Table 8 for Scenario description

TABLE B4

Summary of 8-hour Design Storm Simulation for Scenario 3, Seal Half Kanturk

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.77	77.71	77.70
10-yr 8-hr	6.2	78.47	78.39	78.37
25-yr 8-hr	7.4	79.62	79.48	79.40
100-yr 8-hr	8.9	81.08	80.85	80.72

Please refer to Table 8 for Scenario description

TABLE B5

Summary of 8-hour Design Storm Simulation for Scenario 4, Weir in Killarney

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.90	77.45	77.26
10-yr 8-hr	6.2	78.45	77.94	77.82
25-yr 8-hr	7.4	79.42	78.83	78.68
100-yr 8-hr	8.9	80.65	79.90	79.66

Please refer to Table 8 for Scenario description

TABLE B6

Summary of 8-hour Design Storm Simulation for Scenario 5, 1mgd Supplemental Water

Killearn Chain of Lakes Hydrologic Investigation

Design Storm	Rainfall (in)	Lake Kinsale (ft)	Lake Killarney (ft)	Lake Kanturk (ft)
5-yr 8-hr	5.5	77.78	77.72	77.70
10-yr 8-hr	6.2	78.48	78.39	78.37
25-yr 8-hr	7.4	79.63	79.48	79.41
100-yr 8-hr	8.9	81.08	80.86	80.72

Please refer to Table 8 for Scenario description