DEPARTMENT OF NATURAL RESOURCES

Modeling Analyses Required by Ramsey County District Court Order 62-CV-13-2414, Parts 3.A) and 3.C)

08/30/2018

PROFESSIONAL GEOLOGIST

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the Laws of the State of Minnesota.

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Executive Summary

The Department of Natural Resources (DNR) is continuing its efforts to manage the public trust resources of White Bear Lake and the adjacent aquifers, and working with local communities, businesses and residents to ensure reliable access to clean, affordable water.

In the past several months, the DNR has achieved a significant benchmark in these efforts by developing an updated groundwater model (the revised, transient North Metro Lakes Groundwater model (NMLG)) that provides the best available science to inform ongoing discussions and decisions about groundwater management. The new model allows the DNR and communities to evaluate, for the first time, the cumulative and individual effects of permitted groundwater pumping on water levels within White Bear Lake. The model also adds to the available tools for evaluating effects of groundwater appropriations on aquifer levels.

This report describes the DNR's application of the groundwater model and analysis of groundwater appropriation permits within 5 miles of White Bear Lake as directed by Ramsey County District Court Order 62-CV-13-2414 Parts 3.A) and 3.C).

> *3.A) Review all existing groundwater appropriation permits within a 5-mile radius of White Bear Lake, analyzing them both individually, and cumulatively, to ensure compliance with the sustainability standard of M.S. §103G.287, subd. 5. The specific results of the analysis will be published in a public newspaper, in a form understandable to the general public.*
>
> *3.C) Analyze the cumulative impact of these permits within the 5-mile radius of White Bear Lake to determine whether pumping at the maximum rates allowed by the permits is sustainable. The specific results of the analysis will be published in a public newspaper, in a form understandable to the general public.*

Minnesota Statute § 103G.287, subd. 5 (Sustainability standard) states:

> *The commissioner* [of DNR] *may issue water-use permits for appropriation from groundwater only if the commissioner determines that the groundwater use is sustainable to supply the needs of future generations and the proposed use will not harm ecosystems, degrade water, or reduce water levels beyond the reach of public water supply and private domestic wells constructed according to Minnesota Rules, chapter 4725.*

In December of 2016, the DNR established the protective elevation for White Bear Lake at 922 feet above mean sea level (MSL). As required by Minnesota Statute § 103G.285, subd. 3(b), this elevation was established after considering the long-term, historic water levels of the lake, important vegetation characteristics, fish and wildlife habitat, water quality, and uses of the lake by the public and riparian landowners (e.g. recreational uses, such as access, boating and swimming).

The DNR conducted additional analysis using the newly available groundwater model. Our analysis applies to the following indicators that relate to criteria set forth in Minnesota Statute and Rule:

- changes to the area of the littoral zone,
- changes to the area of submerged vegetation,

- changes to the nearshore area suitable for emergent plants,
- safe yield for artesian conditions (Minnesota Rules part 6115.0630, subp. 16) for the Prairie du Chien aquifer, and

In addition, the DNR analyzed changes in water levels relative to the protective elevation, which was set to include considerations for recreational use.

The DNR's groundwater modeling staff used the revised and updated version of the transient NMLG model[1] (DNR, 2018) to analyze the individual and cumulative impacts of groundwater pumping on aquifer levels and water levels within White Bear Lake. The revised model improves on and updates the transient version of the NMLG model that was developed for the DNR by S. S. Papadopulos and Associates in 2017. An earlier NMLG model was developed by the U. S. Geological Survey (released in 2017). This earlier model only had steady-state simulation capability (i.e., it could not represent changing conditions over time).

The transient NMLG model computes groundwater levels and flows and lake-water budgets from 1981 through 2016. Model inputs can be modified to represent different, hypothetical conditions (e.g., groundwater pumping) over the modeled period. The model period can be extended as input data (climate, pumping, etc.) become available, and the DNR may make such updates in the future.

Projecting a hypothetical scenario onto the past is a standard and effective way to evaluate the effects of current or proposed appropriations. The same climate data (available observations) are used in all model scenarios, allowing the computed effects of different appropriations scenarios to be compared. In this case, use scenarios applicable to parts 3.A) and 3.C) of the Order were compared to a hypothetical *no use* scenario that served as the reference condition. Developing each scenario required projecting a hypothetical pumping "history" onto the historical model runs for each permitted well. These scenario-pumping histories were applied from 1988 through 2016 (the part of the model period covered by records in the MPARS water-use database) following a model "warm-up" period from 1981 through 1987.

As of August 2018, there are 44 groundwater appropriation permits with at least one groundwater extraction installation (well, drain, etc.) within five miles of the perimeter of White Bear Lake. One of these permits (permit 2006-0618) is for a gravity drainage system with no means to manipulate withdrawal rates.

Public water-supply systems within the evaluated set of permits have experienced moderate growth, no growth, or reduction in population served over the last 10 years (2008 through 2017). Where there has been population growth, the increased population has been effectively offset by reduced per-capita water demand during this period, resulting in steady or decreased water use even where there has been population growth. Improvements in water conservation and use efficiency contributed to reductions in per-capita water demand over this period, but weather-related, lower irrigation demand over the previous four years was also a factor. Changes in irrigation demand due to variable weather is one of the main drivers of year-to-year variation in per-capita water demand. The 10-year, 2008 through 2017 period includes years with relatively high irrigation water

[1] The model was reviewed in a meeting with technical advisors from the Minnesota Pollution Control Agency, Metropolitan Council, and S. S. Papadapulos & Assoc. (SSPA) on July 17, 2018 and is documented in DNR (2018).

demands (i.e., dry summer periods) while also reflecting recent improvements in water conservation and use efficiency. The broader trend of using less water factors significantly in the model results.

The DNR's modeling analysis considered four different pumping scenarios applied to groundwater appropriation permits within 5 miles of White Bear Lake as follows:

1) a no-pumping scenario (i.e., *no use*), which serves as a reference condition. This scenario simulates how the aquifer and lake levels would have been different if no groundwater pumping occurred starting in 1988.

2) a scenario representing permitted groundwater appropriations as they exist (*existing permits*), including the reported water use for the ten years including 2008 - 2017;

3) a scenario in which the currently permitted, maximum annual volumes (*maximum*) were pumped in every year since 1988; and

4) a scenario that considers the effect of the residential irrigation ban prescribed in the Ramsey County District Court Order applied to the *existing permits* scenario, which would have been triggered by White Bear Lake water levels from 2007 through 2016 (*residential irrigation ban*).

The effect of modified pumping rates in the different scenarios takes time to propagate through the modeled groundwater and lake system. This is consistent with the expected behavior of the real system due to the large geographic extent of the groundwater system, multiple aquifers and pumping at varied distances from White Bear Lake. Therefore, model analysis results are shown beginning in 2002, 14 years after hypothetical pumping histories began.

- As expected, the calculated (i.e., predicted) lake stages for the *no use* scenario were higher than both the observed stages and the lake stages for the *existing permits* scenario. Observed, average April-November lake levels fluctuated between 925 and 920 feet from 2002-2016. Under the *no use* scenario, Average April – November lake levels would have fluctuated between 926 – 923.5 feet above mean sea level, and may have reached levels in 2002 as high or higher than any levels measured since 1943.

- Calculated lake stages for the *existing permits* scenario remained above observed lake stages. Average April – November lake levels from 2002 - 2016 would have fluctuated between 925 – 921 feet above mean sea level.

- Calculated lake stages for the stage-triggered, *residential irrigation-ban* scenario from 2007 through 2016 were 0.01 to 0.4 feet above the corresponding stages for the *existing permits* scenario, from which it was derived.

- Calculated lake stages for the *maximum* pumping scenario would have been lower than the observed conditions. Average April – November lake levels from 2002 – 2016 would have fluctuated between 924 - 918.5 feet above mean sea level. *Note: the maximum scenario in this analysis, in which the maximum authorized volumes are pumped every year, far exceeds any realistic pumping scenario under the existing permits.*

- The calculated acreage of the littoral zone area at the average, April - November stage was greater for the *existing permits* scenario than for the reference, *no use* scenario throughout the 2002-2016 period.

- During the year with the lowest estimated April - November water levels, the littoral zone area was 11 percent less in the *maximum* scenario than in the *no use* scenario. This is less than the 15 percent regulatory threshold for aquatic plant pesticide control set forth in Minnesota Rules part 6280.0350, subp. 4 [2].

- The emergent aquatic plants in White Bear Lake benefit from, and in fact need, periodic fluctuations in water level to persist.

- For all scenarios, computed heads in the Prairie du Chien aquifer remained well above the top of the aquifer, and collective pumping rates remained well below the long-term average groundwater recharge rates.

- Calculated lake stages indicate that the past (reported) groundwater use has resulted in water levels going below the protective elevation, which is established at 922 feet above mean sea level (MSL).

- The individual permits analysis confirmed that the effects of pumping associated with 7 of the 44 permits dominate the collective effects on White Bear Lake water levels.

In summary, our analysis of littoral zone habitats, submerged aquatic vegetation and areas of emergent aquatic vegetation under the various pumping scenarios indicates that authorized pumping would not result in harm to the lake ecosystem. It also indicates there is no risk of exceeding safe yield for artesian aquifers or for the water table under the currently existing permits that authorize groundwater pumping within 5 miles of White Bear Lake.

While existing permits meet the statutory sustainability requirements as described above, past pumping resulted in water levels that dropped below the protective elevation set by the DNR during the 2007 through 2015 period. The new groundwater model will be extremely useful as the DNR works with local communities, businesses and residents to consider carefully targeted, well-informed modifications to water use in the area to limit impacts to the recreational uses that the protective elevation is also designed to support.

[2] The 15% limitation on disturbance of vegetation in littoral zones set forth in Minn. R. 6280.0400, subp. 4 is a "conservative estimate" of the amount of vegetation disturbance permitted in the littoral zone by riparian landowners (Statement of Need and Reasonableness (SONAR) in the Matter of the Amendment of Proposed Rules Relating to Aquatic Nuisance Control Chapter 6280, at 20, December 19, 1995). This 15 % threshold was set as the maximum amount of permitted vegetative disturbance in the littoral zone to assure habitat preservation, prevent shoreline erosion, cycle nutrients, provide oxygen, improve water clarity, and stabilize bottom sediments (Id. at 1-2 and 20).

Introduction

The DNR is continuing its efforts to manage the public trust resources of White Bear Lake (WBL) including its surrounding aquifers, and working with local communities, businesses and residents to ensure reliable access to clean, affordable water.

In the past several months, the DNR has achieved a significant benchmark in these efforts by developing an updated, complex groundwater model that provides the best available science to help inform future discussions and decisions around groundwater management. The new model allows the DNR and communities to evaluate, for the first time, the cumulative and individual effects of permitted groundwater pumping on water levels within WBL.

This report describes groundwater-lake modeling analyses that the Minnesota Department of Natural Resources (DNR) completed to fulfill the requirements of Ramsey County District Court Order 62-CV-13-2414 (Order) Parts 3.A) and 3.C). These parts of the Order state that the DNR shall:

> *Review all existing groundwater appropriation permits within a 5-mile radius of White Bear Lake, analyzing them both individually, and cumulatively, to ensure compliance with the sustainability standard of M.S. §103G.287, subd. 5. The specific results of the analysis will be published in a public newspaper, in a form understandable to the general public.*

And

> *Analyze the cumulative impact of these permits within the 5-mile radius of White Bear Lake to determine whether pumping at the maximum rates allowed by the permits is sustainable. The specific results of the analysis will be published in a public newspaper, in a form understandable to the general public.*

There are 44 groundwater appropriation permits with at least one groundwater-extraction installation (well, drain, etc.) within five miles of the perimeter of WBL (Figure 1). One of these permits (permit 2006-0618) is for a gravity drainage system with no means to manipulate withdrawal rates.

The model was the revised version of the triannual NMLG model[3] (DNR, 2018) that uses U.S. Geological Survey computer-modeling code (Niswonger et al., 2011). The model computes groundwater levels and flows and lake-water budgets from 1981 through 2016.

The original NMLG model, which was developed by the U. S. Geological Survey Minnesota Water Science Center under contract with the Metropolitan Council (Jones et al., 2017), had only steady-state capability (i.e., it could not simulate changing conditions over time). DNR contracted with S. S. Papadopulos & Associates in 2017 to add transient simulation capability and make necessary and appropriate modifications to improve the model fit to

[3] The revised model was reviewed in a meeting with technical advisors from the Minnesota Pollution Control Agency, Metropolitan Council, and S. S. Papadapulos & Assoc. (SSPA) on July 17, 2018 and is documented in the cited report.

transient data (SSPA, 2017). There were two model versions with annual and triannual (three per year) time steps.

Following completion of the initial transient model analysis and report by S. S. Papadapulos & Assoc., new information and data became available. DNR staff reviewed the model and conducted additional data and model analyses. DNR staff revised the transient NMLG model to incorporate: revised WBL evaporation observations and modeling analysis published by researchers at the University of Minnesota (Xiao et al., 2018), a revised parameterization of the model used to compute groundwater recharge, a revised stage-volume-area table for WBL that incorporates LiDAR-based elevation data, other model feature improvements, and revised parameter estimates that take into account the other model revisions. See the full report for details (DNR, 2018).

Like any model of a natural system, the revised NMLG model is a simplified and imperfect representation of the hydrologic system in the northeastern Metro area with limitations in the data inputs and the model's ability to represent actual hydrologic conditions. The revised model does not represent a unique solution, but it incorporates improvements and new data. This included revised inputs that are important to the WBL water budget such as lake evaporation and also included more tightly constraining some sensitive hydrogeological property parameters to the expected range of values. Despite their differences, the SSPA and revised models computed similar cumulative impacts of historical groundwater pumping on WBL water levels. Although there is uncertainty in the calculated lake stages due to model predictive uncertainty, one may be confident in the relative ranking of the calculated lake stages for the analyzed scenarios, both in relation to each other and to historical observations. In addition to uncertainties in model representation of the hydrologic system, there are also significant uncertainties in future climate and other conditions that affect lake levels. Changes to groundwater pumping may have more or less effect on lake stages than computed by the model.

Projecting a hypothetical scenario onto the past is a standard and effective way to evaluate the effect of current or proposed appropriations. Developing each scenario required projecting a hypothetical pumping "history" onto the historical model runs for each permitted well. These scenario-pumping histories were applied from 1988 through 2016 (the part of the model period covered by water-use records in the MPARS database) following a model "warm-up" period from 1981 through 1987. The warm-up period reduces the effects of the initial, steady-state period (pre-1981) and estimated pumping rates for most permits prior to 1988.

There were four cumulative pumping analysis scenarios in which modeled pumping representing permits within 5-miles of WBL was modified: a no-permitted groundwater-appropriations scenario (*no use*); a scenario representing permitted groundwater appropriations as they exist (*existing permits*); a scenario in which the currently permitted, maximum authorized volumes (*maximum*) were pumped in every year; and a scenario representing existing, permitted groundwater appropriations modified to represent a WBL stage-triggered irrigation ban for municipal/public water-supply permits from 2007 through 2016 (*residential irrigation ban*). The *residential irrigation-ban* scenario represents Order part 4.C).

In addition to the scenarios analyzing collective pumping under all of the permits, the annual version of the revised NMLG model was used to run an individual scenario for each of the 44 existing permits as part of the *existing permits* analyses.

Calculated lake levels were used to assess potential changes to the littoral zone and nearshore area of WBL and to assess compliance with safe yield for the Prairie du Chien aquifer, which were the criteria applied as indicators of ecological impacts and aquifer sustainability.

Analysis Methods

Evaluation Criteria

M.S. § 103G.287, Subd. 5 (Sustainability standard) states:

> *The commissioner* [of DNR] *may issue water-use permits for appropriation from groundwater only if the commissioner determines that the groundwater use is sustainable to supply the needs of future generations and the proposed use will not harm ecosystems, degrade water, or reduce water levels beyond the reach of public water supply and private domestic wells constructed according to Minnesota Rules, chapter 4725.*

In determining whether the sustainability standard of section 103G.287, subd. 5 is met as required by Parts 3.A) and 3.C of the Order, the following indicators were applied:

- changes to the area of the littoral zone,
- changes to the area of submerged vegetation,
- changes to the nearshore area suitable for emergent plants, and
- safe yield for artesian conditions (Minnesota Rules part 6115.0630, subp. 16) for the Prairie du Chien aquifer.

Water quality and risk for well interference also apply to the Sustainability standard. Existing information on these criteria is sufficient, and they required no further analysis. Existing information on polluted groundwater plumes, well interference complaints, analyses conducted for permit and water supply plan reviews, and water quality in WBL were reviewed.

The risk for adverse impacts to groundwater quality through effects on the migration of polluted groundwater plumes and the risk for well interference are considered in permit and water-supply plan reviews conducted by DNR. These are primarily local-scale issues. The DNR also consults with the Minnesota Department of Health and the Minnesota Pollution Control Agency when considering potential impacts of groundwater pumping on polluted groundwater plumes.

In December of 2016, the DNR established the protective elevation for WBL at 922 feet above mean sea level (MSL 1912) (DNR, 2016). This elevation was established after considering the long-term, historic water levels of the lake, important vegetation characteristics, fish and wildlife habitat, water quality, and uses of the lake by the public and riparian landowners in accordance with the criteria in Minnesota Statute § 103G.285, Subd. 3(b).

For the protective elevation analysis the DNR reviewed available data on phosphorous concentrations and water clarity in WBL, and the DNR concluded that, "*no significant patterns were found between the lake's water elevation, and water clarity or water quality over the period of record examined*" (DNR, 2016). No further assessments of risk for degradation of water were completed for the present analysis.

This report focuses on evaluating the criteria of the Sustainability standard (Minnesota Statute § 103G.287, Subd. 5) as directed in Order parts 3.A) and 3.C). Lake levels can affect recreational activities like riparian access, navigation, and swimming. The DNR did consider impacts to recreation and navigation in setting the protective elevation for WBL. In fact, recreational uses factored significantly in setting the protective elevation. In the findings of fact, the DNR (2016) found that “there is no evidence to support a conclusion that setting a protective elevation at or above WBL’s historic low is necessary to protect the lake’s ecological health.” Therefore, in addition to assessing compliance with the Sustainability standard, we note the positions of calculated lake levels in relation to the protective elevation for each scenario.

Scenario Pumping Histories

Projecting a hypothetical scenario onto the past is a practical and effective way to evaluate current or proposed appropriations. Developing each scenario required projecting a hypothetical pumping “history” onto the model runs for each permitted well. The triannual NMLG model runs an initial, steady-state period followed by transient computations with three stress periods per year from 1981 through 2016. In each stress period, model-forcing inputs such as groundwater recharge, pumping, lake precipitation, and lake evaporation are held constant, representing the average over a four-month period. As noted in the original model report (SSPA, 2017), pumping data are most complete and accurate starting in 1988, when the DNR initiated an electronic water-use database. Each pumping history consisted of these components:

- Unmodified, reported or estimated pumping for the initial and 1981 through 1987 periods,
- Backfilled, replaced, or unmodified pumping (as appropriate for each scenario and permit) beginning in 1988, and
- Unmodified pumping for the latter part of the run through 2016 that is representative of existing pumping.

The effect of modified pumping rates in the different scenarios takes time to propagate through the modeled groundwater and lake system, reflecting the expected behavior of the real system. Therefore, analysis results are shown beginning in 2002, 14 years after modifications to hypothetical pumping histories began. The sustainability assessment focused on the period of relatively lower WBL levels from about 2008 through 2015. Focusing on these later years allowed time for changes starting in 1988 to propagate through the system and minimized the influence of year-to-year pumping variations prior to the focus period. The difference in lake stage between a collective, <u>*no use*</u> scenario and the baseline model representing actual pumping history peaked during this period (See the revised model report, DNR, 2017).

The analysis did not factor in potential differences in land and water use other than direct groundwater withdrawals.

Precipitation-infiltration recharge was calculated using the Soil Water Balance (SWB) modeling code (Westenbroek and others, 2010). The SWB model did not factor in the effect of irrigation water applied to the land surface. This is a conservative approach because the increased soil moisture from irrigation (which is mostly sourced from groundwater) enhances groundwater recharge. This should be considered when applying analysis results.

The amount of pumped groundwater used for irrigation is uncertain because municipal/public- and private-water supplies deliver water for a variety of uses, including irrigation. DNR estimated irrigation under municipal/public-water supplies for the analyses conducted previously by SSPA (2017) using a method developed by the Metropolitan Council that compares water use in January through March to water use in June through August of the same year. Note that this estimation method likely includes other summer water uses in addition to residential irrigation. Combining these estimates with other permits that include irrigation use, the estimated pumping used for irrigation was from 8 to 25 percent (average of 18 percent) of the total reported pumping for the analyzed permits from 1988 through 2016.

The forward-looking analyses also did not project current land use onto the past. The latter simplification is expected to have a relatively small effect on the analysis because the effects of changes in land use since 1988 on recharge in the area of interest are expected to be modest. There is also significant uncertainty in how accurately the effects of changing land use on recharge are estimated with the SWB model.

Reference Condition

To evaluate impacts, a reference scenario must be developed for comparison. To evaluate existing groundwater appropriation permits in relation to the Sustainability Standard, a *no use* scenario was developed in which all existing and terminated permits with one or more groundwater withdrawal installations within five miles of WBL were shut off from 1988 through 2016.

In the analyses reported by SSPA (2017), the appropriate reference scenario was the base model designed to represent actual pumping history. SSPA only modified existing permits because the purpose of the analyses was to evaluate the relative, historical impacts of existing permits on lake stage. The analyses did not modify permits that were terminated before 2016. Removing the terminated permits in the *no use* scenario for the present analysis had a relatively minor impact on computed lake stages, but it is a more exact representation of a reference condition.

Existing Permits Scenario

The *existing permits* scenario represents withdrawals for groundwater appropriation permits under recent/current conditions. A number of permits were either initiated or amended, or use patterns changed during the analysis period (1988-2016). Some permits were terminated. Permit histories were backfilled or replaced for any portion of the period from 1988 through 2015 that was not representative of the existing uses. The types of backfilling/replacements to pumping histories are discussed below and are summarized in Table 1.

Municipal/Public Supply Permits

Public water-supply systems within the evaluated set of permits have experienced moderate growth, no growth, or reduction in population served over the last 10 years (2008 through 2017). Where there has been population growth, the increased population has been effectively offset by reduced per-capita water demand during this same period. Reductions in water use were most pronounced over the last four years, but none of these years had high irrigation demands, one of the main drivers of year-to-year variation in per-capita demand. The 10-year, 2008 through 2017 period includes years with relatively high water demands while also reflecting recent improvements in water conservation and use efficiency. Therefore, the 2008 through 2017 period as a whole is representative of existing use under the municipal/public supply permits. These characteristics of municipal/public supply permits are generally evident in the total, collective annual volumes for all of the permits (Figure 2).

For municipal/public supply permits, the 1988 through 2016 pumping history was developed by:

- Replacing the volume in each year from 1988 through 2007 with the 2008 through 2017 average and,
- Retaining the reported volumes for 2008 through 2016.

Note that the model period ends in 2016, but, for the purpose of calculating the 10-year average to represent existing/recent conditions in the 1988 through 2007 model period, 2017 pumping records were included. Two examples are shown in Figure 3. The model period could be extended in the future. The relative proportion of pumping in each triannual stress period within each year was retained throughout the simulation. St. Paul Regional Water Services (SPRWS) uses groundwater differently than other municipal systems, however, and it was treated as described below under Terminated and Reduced Permits.

Some wells were sealed or added to permits in the last 10 years. For these permits, average total volume from 2008 through 2017 was still used for the 1988-2007 period, but the total volume was distributed among the wells based on the current well configuration. For example, Mahtomedi first used its newest well (Well 6) in 2009. The average fraction of the total pumping for each well from 2009 through 2017 determined the proportion of the 2008 through 2017 average volume to apply to each well in the 1988 through 2007 replacement period. Reported pumping from each well for 2008 through 2016 was retained. Because there was only one year (2008) during this period without Well 6, no adjustment to individual well pumping during 2008 through 2016 was warranted for this permit. For some permits, changes in the well configuration would not have a significant effect and were ignored because the wells within a well field are close together relative to their distance to WBL.

Terminated and Reduced Permits

In scenarios designed to evaluate existing permits in a forward looking sense, proposed new permits, or amendments, terminated permits should be shut off for the entire analysis period. This appropriately projects only existing permits onto the analysis period for comparison against the reference condition.

Three permits had reductions in permitted annual volume within the analysis period: St. Paul Regional Water Services (SPRWS), White Bear Township, and Sawmill Golf Club. The amendments were considered when developing the volume histories for these permits.

SPRWS (permit 1977-6229) used groundwater in addition to its primary surface water sources since wells were first installed in 1977. Groundwater served several purposes for the system, but, until recently, the collective capacity of the SPRWS wells was much less than the average system water demand. Beginning in 2004, SPRWS expanded its well field with the goal of providing an adequate back-up supply in the event of an emergency disruption in its surface water sources. DNR amended the authorized volume under permit 1977-6229 in 2006 and again in 2008 to accommodate potential demands during an emergency. SPRWS continued to pump groundwater but at a small fraction of the authorized maximum volume.

SPRWS has recently changed its approach to the use of groundwater. Its authorized groundwater appropriation volume was amended from 16,800 million gallons per year (MGY) to 2,500 MGY in 2016. SPRWS plans on using groundwater only as a backup when the surface water supply is disrupted, however. In the event of an extended emergency, SPRWS would be authorized to exceed the annual appropriation volume of 2,500 MGY, if necessary. SPRWS reported zero groundwater use in 2015 and 2016. A construction project in fall 2017 disrupted access to water sourced from the Mississippi River, necessitating that SPRWS use groundwater. After notifying DNR that it would use less than 2,500 million gallons of groundwater, SPRWS appropriated groundwater for less than two months to replace its surface-water supply. The 2017 project was an unusual occurrence, and no significant groundwater pumping volume is the most representative of current and future appropriations by SPRWS. Therefore, for the *existing permits* scenario, pumping reported for 1988 through 2014 was replaced with zero (Figure 4).

White Bear Township's permit (1984-6121) was temporarily amended from 2005 through 2007 to allow a maximum annual volume of 650 MGY (up from an authorized maximum volume of 450 MGY prior to 2005). This exceeds the currently authorized maximum volume of 550 MGY. Water demands have declined in recent years. The 2008 through 2017 average use appears to represent or exceed current average demands, and this permit was treated in the same way as other municipal permits for the *existing permits* scenario (i.e., the reported use from 1988 through 2007 was replaced with the 2008 through 2017 average).

In 2016, the appropriation to Sawmill Golf Club (permit 1990-6325) was split because the golf course was divided in two, splitting off the Loggers Trail Golf Course. The Loggers Trail Golf Course was issued a separate permit (2016-0437) authorizing it to use 25 MGY. At the same time, the permit for Sawmill Golf Club (permit 1990-6325) was reduced from 66.8 MGY to 30 MGY. The total for the two permits (55 MGY) is less than the previously permitted volume. The maximum, historical use under permit 1990-6325 was 49.5 MGY. Past use during the period for which permit 1990-6325 was authorized to use up to 66.8 MGY (2003-16) appears to be representative of the total use under the two existing permits. Therefore, no adjustments were made during this period. An amendment to increase permit 1990-6325 in 2002 was treated in the same way other upward amendments were treated (discussed below).

New or Changed Permits

Several permits were initiated, amended upward, or had changes in use patterns during the period analyzed. These permits were treated similarly to municipal permits to adjust pumping histories. For these permits, either 2008 through 2017 or an appropriate, alternative period, based on changes to the permit and/or use patterns, defined the representative average for earlier periods. If the permit was initiated or last amended after 1988, the average was used to backfill missing data or replace years before the use change. As for municipal permits, the current well configuration was applied to backfilled or modified periods.

For example, no water was used under industrial permit 2003-3036 from early 2015 through 2017 because operations shut down. Nevertheless, this remains an active permit at this time. The 2008 through 2014 average use was used to backfill the pumping history during the period before the well for this permit was first used (1988 through 2000).

Other Permits

Permit 2006-0618 is for a gravity drainage system beneath a section of State Highway 36. Because this is a gravity system with no pumps, modifying pumping history does not make physical sense. Nearly all of the total volume reported under this permit to date was drained over a period in 2007-08 immediately after the system was installed. Since 2008, reported drainage has been less than 1.2 MGY and has been less than the permit threshold of 1 MGY since 2011. This permit may be terminated in the future if drainage does not again approach 1 MGY, but it has so far been maintained because drainage slightly exceeded 1 MGY in 2010 and 2011. Given the nature of this appropriation, the reported drainage volumes were not modified for the _existing permits_ and _maximum_ scenarios.

Other permits were either not amended and/or did not experience persistent changes in use pattern during the analysis period. For these permits, reported pumping volumes were applied without adjustment. Pumping volumes for permitted pollution-containment systems was also left unmodified.

Individual Permits Analysis

In addition to analyzing the cumulative effects of the existing groundwater appropriation permits, the Order also requires that they be analyzed individually. Individual model runs were performed for each of the 44 permits using the revised annual NMLG model, similar to the “Scenario 1” runs completed by SSPA for the original model report (SSPA, 2017).

In each run, pumping under an individual permit was shut off beginning in 1988. All other pumping remained the same as in the _existing permits_ scenario. The differences in the computed WBL stage between each run and the _existing permits_ scenario was calculated and plotted.

It should be noted that the calculated stage differences for a particular permit depend on/have a feedback relationship with the lake stage and groundwater levels (as affected by all influences on the lake and groundwater), not just the amount of groundwater pumped under that particular permit. Therefore, the stage differences for an individual permit cannot be uniquely determined. The calculated stage differences for the analyzed permits are representative, however, particularly in their relative rankings.

Maximum Scenario

“Pumping at the maximum rates allowed by the permits” that authorize pumping of groundwater within the designated area was represented using the currently authorized, maximum annual volumes. This included 43 of the 44 groundwater appropriation permits. Reported drainage for the 44th permit (2006-0618) was applied rather than the authorized maximum volume because this is a passive, gravity-driven system. Short-term pumping at the instantaneous maximum rates cannot be analyzed with the groundwater model that operates with triannual (i.e., four-month) stress periods. Analyzing short-term effects was not necessary, however, because impacts to WBL water levels and any “progressive decline in water pressures and levels” in the aquifer (Minnesota Rules part 6115.0630, subp. 16) depend on the cumulative effect of pumping over longer time periods.

In reality, actual water use varies from year to year for each permit, and, longer-term, collective total water use is far less than the collective maximum authorized volume. Although uses under existing individual permits have occasionally equaled or exceeded the authorized maximum volumes, there has not been a year from 1988 through 2017 (the period covered by the MPARS database) in which the maximum authorized volume at the time was exceeded individually by all of the 44 analyzed permits or in which the collective volume pumped exceeded the collective authorized volume, either as permitted at the time or as currently permitted (Figure 2). Pumping the maximum authorized volume every year is clearly an exaggerated scenario.

There are a variety of reasons why actual groundwater pumping is typically less than authorized volumes for individual permits. For many permits, the water demand varies from year-to-year, but the authorized maximum allows for the greatest annual water use that may occasionally occur. The authorized maximum may allow groundwater users to respond to rare emergencies, such as firefighting or emergency inter-connections with other communities, without violating the permit. The authorized maximum volumes may also allow for near-term, projected population growth and associated water demand.

Although the collective, average groundwater use has been substantially less than the collective authorized maximum permitted use and is expected to hold steady or continue to decrease in many communities, groundwater use in some communities may exceed recent use due to population growth. Therefore, future use is projected to exceed recent use for those permits without requiring a permit amendment. Even with authorized water-use growth, however, average use would remain well below the currently authorized maximum, both for those individual permits and collectively for all the permits. Because the ***maximum*** scenario does not reflect a foreseeable reality, DNR computed the maximum scenario solely to comply with the Order.

For permits allowing year-round appropriations, the annual volume was evenly distributed through the year. For irrigation permits, the volume was evenly applied over the two warm-season stress periods (April-July and August-November). A more complex distribution over the triannual stress periods in each year was not warranted because this scenario is disconnected from actual or realistic water demands, and longer term (i.e., multi-year) pumping effects are more important than seasonal variations. For permits with multiple wells, volumes were distributed among the wells based on the average distribution during the time having the current well configuration or the last 10 years, whichever period was the shorter.

Residential Irrigation Ban Scenario

Part 4.C) of the Order requires:

> *Preparing, enacting and enforcing a residential irrigation ban when the level of White Bear Lake is below 923.5 feet, to continue until the lake has reached an elevation of 924 feet.*

The effect of appropriation reductions based on a residential irrigation ban can only be estimated because the amount of pumping for residential irrigation is not tracked separately from other residential water uses. In addition, municipalities report data on the total annual water use for several use categories including residential, but monthly volumes are reported only as total water pumped. Therefore, the available data do not allow one to compare residential water use during the irrigation season to residential water use during the remainder of the year.

As described earlier under Scenario Pumping Histories, irrigation use associated with municipal/public water supply permits was approximated for each municipal/public water supply permit as the increase in average pumping from June through August over average pumping from January through March of the same year. Small institutional and private water supply pumping was not modified in this evaluation of irrigation pumping effects, but the volumes pumped under these permits are small and showed negligible effects in the individual permits analysis (See Results below). The estimated municipal/public water supply irrigation volumes, however, are expected to include commercial and institutional irrigation as well as other water uses that tend to be larger in the summer. As mentioned above, the analysis did not factor in the increase in groundwater recharge caused by irrigation.

In the *existing permits* scenario, the calculated lake stage was 923.4 feet (MSL 1912) near the end of 2006 and remained below 924 feet (MSL 1912) through the remainder of the model run to the end of 2016 (See Results below), which would have triggered the residential irrigation ban from 2007 through 2016. Therefore, estimated irrigation was removed from municipal/public water supply pumping volumes during this time period (from 2007 through 2016). Because the *existing permits* scenario retained actual, reported pumping from 2008 through 2016, we estimated irrigation for each permit in each year as described above for all the irrigation ban years except 2007.

Recall that, in the *existing permits* scenario, the 2008 through 2017 average pumping volumes for municipal/public water supply permits were applied from 1988 through 2007. To include 2007 in the *residential irrigation ban* scenario, we needed to reduce municipal/public water supply pumping volumes in 2007 by amounts that represented irrigation. To do this we first calculated the average ratio of June through August pumping versus January through March pumping for each permit over the 2008 through 2017 period. We then used these average ratios to reduce the pumping associated with each permit in the triannual model periods that included the months of June through August 2007.

Calculated Lake Hydrographs

DNR used a computer program developed by SSPA, separate from the NMLG model, that combines model-computed lake budgets with observed lake levels to calculate estimated WBL hydrographs for each scenario (as in the hydrographs shown in Figures 8-3 and 8-4 in the SSPA, 2017 report). This removes some of the error in model-computed lake stages while accounting for the lake outlet.

The program calculates, for each stress period, the differences in lake and surface outflow volumes between a hypothetical model scenario and the baseline model run representing actual historical conditions. The errors in these differences between model scenarios is generally expected to be less than the errors in the absolute lake stages and volumes calculated by the NMLG model. The program then adds these volumes (i.e., the differences in volumes) to lake and surface outflow volumes calculated directly from observed lake stages and iteratively solves for the corresponding lake stage and surface outflow. In making this calculation, the program uses the same lake stage-volume-area and stage versus surface outflow tables used in the NMLG model.

Littoral Zone Analysis

For this analysis, DNR calculated the area of the littoral zone at the average, April through November water level. This represented an index of the littoral zone during the open-water season and could be readily calculated from triannual model results. The littoral zone area is the difference between the water surface area and the area at an elevation 15 feet below the water level. The amount of area with submerged vegetation was estimated by multiplying the probability of vegetation occurrence within 2-foot depth intervals (e.g., 0-2 foot, 2-4 foot, etc.) times the area within each depth interval. The probabilities of vegetation occurrence for the depth bins were derived from recent, extensive aquatic plant surveys on six lakes comparable to WBL (Paul Radomski, personal communication) The estimated littoral zone areas and submerged vegetation areas for each pumping scenario and the observed lake stages were compared to the estimated areas of the reference, *no use* scenario through calculation of the percent difference.

Near-Shore Area Analysis

DNR staff in the Lake Ecology Unit estimated the size of the nearshore area potentially suitable for emergent plants under different stable water level conditions with a spatial analysis of the WBL basin. Contour lines were interpolated to 1-foot intervals in ArcGIS using LiDAR-derived contour lines and lake bathymetry data. For each contour line (i.e., shoreline), the potential nearshore emergent vegetation area was assumed to be that area three feet deeper (lakeward) and one foot shallower (landward) than the contour line. At high water levels, the potential areas sometimes included existing developed areas and other areas not suitable for aquatic plants.

To determine consequences of the different pumping scenarios, the Lake Ecology Unit staff estimated the potential nearshore emergent vegetation area corresponding to the 2002 through 2016 average water level from each pumping scenario and from the observed lake stages. These areas were then compared to the estimated potential nearshore emergent vegetation area of the reference, *no use* scenario for the same time period. While the water levels fluctuated for each scenario, those fluctuations were not used in this latter analysis.

Safe Yield Analysis

The Prairie du Chien and Jordan bedrock aquifers, which are artesian or confined aquifers as defined in Minnesota Rule 6115.0630, Subp. 4, were the focus of the safe yield analysis. The Prairie du Chien is the shallower of the two aquifers that make up this bedrock aquifer system. Therefore, the model-computed head above the elevation of top of the Prairie du Chien was used as the indicator of compliance with safe yield for artesian condition.

Results

Calculated Lake Hydrographs

Calculated lake stages for each pumping scenario along with the observed stages at the end of each triannual stress period are shown in Figure 5. Although there is some uncertainty in the estimated stages due to model predictive uncertainty, one may be confident in the ranking of each scenario relative to the observations and to each other.

Calculated lake stages for the *existing permits* scenario remained above the observed lake stages. The calculated stages became increasingly higher relative to observations from 1988 through about 2007 and then fluctuated between 0.9 and 1.0 feet above observations for the remainder of the analysis period. This is primarily because pumping representing recent water demands was less than historical pumping for some permits with relatively higher influence on WBL stages. The largest change has been to SPRWS groundwater use, which was represented as zero pumping in the *existing permits* scenario. As mentioned under Analysis Methods, removing the permits that were terminated between 1988 and 2016 had a minor effect on the results. Calculated lake stages for this scenario were below the protective elevation of 922 feet from 2009 until 2014. The results of the individual permits analysis are described at the end of the Results section.

Note that the analysis period was 29 years, projected onto the past. Looking forward from actual current hydrologic conditions and assuming groundwater use holds essentially steady, the impact of recent reductions in groundwater use would not fully develop for a number of years until the impacts of past pumping had largely dissipated. The response to largely discontinued pumping by SPRWS will be particularly slow because the wells are approximately five miles from WBL and because SPRWS appropriated groundwater for almost 40 years prior to 2015.

As expected, the calculated stages in the *maximum* scenario were below the observed stages. The lowest April-November average, calculated stage was 918.3 feet (MSL, 1912) in 2010 compared to the corresponding observed value of 919.9 feet (MSL, 1912) in the same year. Calculated stages for this scenario were below the protective elevation of 922 feet from 2006 through 2016.

The calculated stages for the *no use* scenario varied from 0.8 to 4.2 feet above the corresponding observed stages during 2002 through 2016. The lowest April-November average, calculated stage was 923.4 feet (MSL, 1912) in 2010. In this scenario lake levels are predicted to remain above the protective elevation of 922 feet (MSL) during the period of analysis (2002 through 2016).

The difference between the calculated stages for the *residential irrigation ban* scenario and the *existing permits* scenario gradually increased from 0.01 feet at the end of 2007 to 0.37 feet at the end of 2016. The lowest April-November average, calculated stage for the *residential irrigation ban* scenario was 921.0 feet (MSL, 1912) in 2010 compared to the corresponding *existing permits* scenario value of 920.9 feet (MSL, 1912).

Littoral Zone Area

Due to the shape of the lakebed, the area of the littoral zone reaches a maximum in the stage range of 920 to 922 feet (MSL, 1912). Because of this, the littoral zone area was greater in 2010 (the year with the lowest average April-November stage) for the *existing permits* scenario and observed stages than it was for the *no use* scenario (Figure 7). The lake stages for the *residential irrigation ban* scenario were marginally different from the *existing permits* scenario, and therefore littoral zone areas for the *residential irrigation ban* scenario are not shown.

The 2010 April-November average stage and corresponding water surface, littoral zone, and estimated submerged vegetation areas estimated for each scenario are listed in Table 2. The estimated littoral zone area and submerged vegetation area for the *maximum* scenario was 11 percent less and 9 percent less, respectively, than the estimated areas for the *no use* scenario.

One should consider uncertainty when applying these results. There are errors in the bathymetry data used to calculate areas, and there are errors due to model predictive uncertainty. Although the model-computed stage differences between the different pumping scenarios are imperfect predictions, the *maximum* scenario is extreme, representing more long-term pumping than would actually occur under existing permits. On balance, the estimated reduction in littoral-zone area of 11 percent under the analyzed, *maximum* scenario is expected to exceed the potential impacts under any realistic scenario representing existing permits.

This analysis suggests that the size of the littoral zone and submerged-vegetation areas, which are critical in supporting fish and wildlife, are not significantly affected over the range of observed lake levels on WBL. In fact, the estimated 11 percent reduction in the littoral-zone area under the *maximum* scenario is less than the 15 percent regulatory threshold for aquatic plant pesticide control set forth in Minnesota Rules part 6280.0350, subp. 4.

Near Shore Area

The potential nearshore emergent vegetation area was estimated to decrease with increasing stable water levels (Figure 8). Again, the shape of the lakebed generates suitable conditions for emergent vegetation at lower water levels (Figure 9). The estimated potential nearshore emergent vegetation area was highest for the *maximum* scenario, whereas the *existing permits* scenario was similar to the reference, *no use* scenario. These results were inverse of the average lake stage (Figure 10). There is some uncertainty in the absolute values of the estimated, potential nearshore emergent vegetation areas resulting from bathymetric-data accuracy and interpolation, but one may be confident in the general trends of the results.

This analysis suggests that the potential areal emergent plant coverage of WBL varies with water levels, that the coverage at a specific location on the lake depends on the littoral slope at the site, that fluctuations in water levels are important, and that the extent of this important fish and wildlife habitat is likely greater at lower lake stages.

Safe Yield

Computed heads in the Prairie du Chien aquifer remained well above the top of the aquifer in the area within 5 miles of WBL for all scenarios. Computed heads were 70 to more than 200 feet above the top of the aquifer in the vicinity of the municipal well fields. For all scenarios, total groundwater pumping was well below the long-term average recharge rate, which is the limit for safe yield for water table condition (Minnesota Rules part 6115.0630, subp. 15). There is no risk of exceeding the safe yield thresholds under the analyzed scenarios.

This is qualitatively consistent with analysis completed by the Metropolitan Council for the 2015 Master Water Supply Plan that analyzed projected 2040 water demands, which in some cases exceeded currently authorized maximum volumes. These pumping rates were applied at steady state (i.e., infinite time) in Metro Model 3. In that analysis, more than 50 percent of the available head in the Prairie du Chien-Jordan aquifer system remained at all of the permitted well locations considered in the present DNR analysis.

Individual Permits

The results of the individual permits analyses are presented in graphs that illustrate the computed relative impact of existing permits on WBL. Figure 11 (top) depicts the calculated differences in lake stage that resulted from shutting off pumping for each one of the permits one at a time while all other pumping remained unchanged from the *existing permits* scenario. As noted previously by SSPA (2017), the pumping associated with a small number of permits likely dominates the cumulative response in WBL. To better illustrate the relative impacts of each permit, Figure 11 (bottom) also shows the calculated stage differences for each permit averaged over the 2008 through 2015 period. The bar chart is sorted from left to right from largest to smallest average stage difference.

As explained in the Analysis Methods section, the stage differences for a particular individual scenario depend on not only the groundwater use under the analyzed permit but also on all other groundwater use in the analyzed scenario. Because of this “nonlinear” system behavior the stage differences between the *no use* scenario and the *existing permits* scenario are not equal to the sum of the stage differences for all of the individual permits model runs (i.e., the collective or cumulative impact on lake stage is not equal to the sum of individual impacts on lake stage). Nevertheless, the individual permit analysis results are illustrative of the relative influence of each permit on lake stage during the period with the largest cumulative effects and relatively lower lake stages.

Summary

The revised, transient NMLG model was applied to analyze four model scenarios for groundwater appropriation permits within 5 miles of WBL: a *no use* scenario, an *existing permits* scenario, a *maximum* scenario, and a *residential irrigation ban* scenario. Each scenario represented hypothetical withdrawals under 44 permits beginning in 1988 in model runs spanning an initial, steady-state period followed by triannual stress periods from 1981 through 2016. The *existing permits* scenario represents long-term pumping at recent/current water demands under existing groundwater appropriation permits. The *maximum* scenario represents long-term pumping at the maximum authorized annual volumes for all of the groundwater appropriation permits (except that reported volumes were applied to one permit because it is for a gravity-driven drainage system).

Calculated lake stages for the *existing permits* scenario remained above historically observed lake stages. The calculated littoral-zone area at the average, April-November stage was greater for the *existing permits* scenario than for the reference, *no use* scenario. Calculated lake stages for the stage-triggered, *residential irrigation ban* scenario from 2007 through 2016 were 0.01 to 0.4 feet above the corresponding stages for the *existing permits* scenario, from which it was derived. The individual permits analysis confirmed that the effects of pumping under 7 to 11 of the analyzed permits dominates the collective effects of all of the analyzed existing permits.

Estimated lake stages for the *maximum* scenario were below historical observations. During the year with the lowest estimated April-November water levels, the littoral-zone area was 11 percent less in the *maximum* scenario than in the *no use* scenario. This is less than the 15 percent regulation threshold for aquatic plant pesticide control set forth in Minnesota Rules 6280.0350, subp. 4, which sets the maximum amount of littoral zone vegetation that may be removed. Although there is some uncertainty in model results, this is expected to be a very conservative estimate of the potential impacts of allowed pumping under the existing permits (i.e., very likely exceeds potential impacts) because the long-term pumping in this scenario far exceeded any realistic scenario under the existing permits.

The analysis of near shore areas suggests that fluctuations in water levels are important for emergent plants and that the potential areal emergent plant coverage of WBL is likely larger at lower lake stages.

Computed heads in the Prairie du Chien aquifer remained well above the top of the aquifer for all scenarios, and collective pumping rates remained well below the long-term average groundwater recharge. There is no risk of exceeding safe yield for artesian aquifers or for the water table under the currently existing permits that authorize groundwater pumping within 5 miles of WBL.

While existing permits meet the sustainability requirements in statute as described above, past pumping has resulted in water levels that drop below the protective elevation, which was set based on potential impacts to recreational uses below an elevation of 922 feet. The new groundwater model will be extremely useful as the DNR works with local communities, businesses and residents to consider carefully targeted, well-informed modifications to water use in the area.

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Table 1 – Summary of changes to reported pumping for each permit for the existing permits scenario and currently permitted volumes

Permit	Land Owner	Use Type	Replacement or Backfill Values	Replacement or Backfill Period	Replacement or Backfill Volume (MGY)	Permitted Maximum (MGY)
1956-0368	RAMSEY COUNTY PARKS and RECREATION	Golf Course Irrigation	None	None	30.4	60
1961-1031	Lake Elmo, City Of	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	124.9	260
1967-0032	Jesuit Retreat House	Commercial/ Institutional Water Supply	None	None	--	3
1969-0163	Mahtomedi, City of	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	261.1	315
1969-0174	City of White Bear Lake	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	883.0	1150
1975-6207	Stillwater, City of-Board of Water Commissioners	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	730.3	865
1975-6218	Hugo, City Of	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	374.2	650
1975-6379	Dellwood Hills Country Club	Golf Course Irrigation	None	None	--	30
1977-6104	Lacasse, Cyril	Agricultural Crop Irrigation	None	None	--	24

Permit	Land Owner	Use Type	Replacement or Backfill Values	Replacement or Backfill Period	Replacement or Backfill Volume (MGY)	Permitted Maximum (MGY)
1977-6176	North St Paul, City of	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	409.8	584
1977-6229	St Paul Regional Water Services	Municipal/Public Water Supply	2015-16 (0)	1988-2014 (replaced)	0	2500
1978-6197	Oakdale, City of - Public Works Dept	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	922.1	1210
1980-6153	Vadnais Heights, City Of	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	483.9	579
1980-6214	HB Fuller	Once-through Systems (HVAC)	None	None	--	185
1984-6120	White Bear Township	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	38.9	65
1984-6121	White Bear Township	Municipal/Public Water Supply	2008-17 Avg.	1988-2007 (replaced)	440.8	550
1985-6123	Town & Country Mobile Home Park, LLC	Private Water Supply	None	None	--	10
1985-6168	Lino Lakes, City Of	Municipal/Public Water Supply	2008-17 Avg. (No re-proportioning of wells after 1997)	1988-2007 (replaced)	498.8	900

Permit	Land Owner	Use Type	Replacement or Backfill Values	Replacement or Backfill Period	Replacement or Backfill Volume (MGY)	Permitted Maximum (MGY)
1985-6321	3M Company	Pollution Containment	None	None	--	60
1986-6165	White Bear Yacht Club	Golf Course Irrigation	None	None	--	60
1986-6211	Gem Lake Hills Inc	Golf Course Irrigation	None	None	--	30
1986-6316	Saputo Dairy Foods USA, LLC	Agricultural/Food Processing	2013-2017 Avg.	1988-2012 (replaced)	163	192
1987-6149	Five Star Mobile Estates L.P.	Private Water Supply	None	None	--	28
1987-6205	Manitou Ridge Golf Club	Golf Course Irrigation	None	None	--	60
1987-6206	Mogrow Inc dba Indian Hills Golf Club	Golf Course Irrigation	Permit max.	1988-90 (totals exceeding max. replaced)	40	40
1987-6207	Mogrow Inc dba Indian Hills Golf Club	Private Water Supply	2008-17 Avg.	1988-2007 (replaced)	14.5	32
1989-6009	Pine Tree Orchard Incorporated	Agricultural Crop Irrigation	None	None	--	16.3
1989-6037	Whirlpool Corp & Reynolds Metals	Pollution Containment	None	None	--	26

Permit	Land Owner	Use Type	Replacement or Backfill Values	Replacement or Backfill Period	Replacement or Backfill Volume (MGY)	Permitted Maximum (MGY)
1990-6325	Sawmill Golf Club	Golf Course Irrigation	2008-17 Avg.	1988-1989 (backfilled), 1990-2002 (replaced)	30.4	30 + 25 (See 2016-0437)
1992-6031	Ind School District 832	Landscaping/Athletic Field Irrigation	None	None	--	17.7
1992-6065	Little Canada, City Of	Landscaping/Athletic Field Irrigation	2008-17 Avg.	1988-91 (backfilled)	1.3	10
1992-6137	North Oaks Golf Club	Commercial/Institutional Water Supply	2015-17 Avg.	1988-1992 (backfilled), 1993-2014 (replaced)	2.8	3.5
1995-6039	Oneka Ridge Golf Course	Other Water Level Maintenance; Golf Course Irrigation	2008-17 Avg.	1988-93 (backfilled)	16.9	91[1]
1995-6119	Costa, Peter	Agricultural Crop Irrigation	2008-17 Avg.	1988-94 (backfilled)	6.4	50
2002-6073	Ind School District 624; Cf Industries Inc	Landscaping/Athletic Field Irrigation	2008-17 Avg.	1988-2001 (backfilled)	3.2	3.5
2003-3036	Veeco	Industrial Process Cooling - Once Through	2008-14 Avg.	1988-2000 (backfilled)	12.8	40
2004-3020	Ind School District 624	Landscaping/Athletic Field Irrigation	2008-17 Avg.	1988-2002 (backfilled)	4.2	5

Permit	Land Owner	Use Type	Replacement or Backfill Values	Replacement or Backfill Period	Replacement or Backfill Volume (MGY)	Permitted Maximum (MGY)
2005-3012	Applewood Hills Golf Course	Golf Course Irrigation	2008-17 Avg.	1988-2003 (backfilled)	21.8	35.3
2006-0618	MnDOT Metro District	Groundwater Dewatering	None	None	--	149.8[2]
2008-0754	Twin Pine Mobile Home Park	Private Water Supply	2008-17 Avg.	1988-2007 (backfilled)	7.8	10
2010-0390	Hill Murray Foundation	Landscaping/Athletic Field Irrigation	2010-2017 Avg.	1988-2009 (backfilled)	2.0	6.4
2010-0445	Hugo, City Of	Landscaping/Athletic Field Irrigation	2010-2017 Avg.	1988-2009 (backfilled)	2.6	7.1
2016-0244	Hedberg, Steve	Nursery Irrigation	Permitted Volume	1988-2015 (backfilled)	1.3	1.3
2016-0437	Logger's Trail Golf Course	Golf Course Irrigation	None (See 1990-6325)	None	--	25

[1] This permit includes both groundwater and surface water sources without separately designated maximum volumes. For the *maximum* scenario, the fraction of the total permitted volume supplied by the groundwater wells was assumed to be 58 percent based on recent water use.

[2] This is a passive, gravity drainage system, and manipulation of appropriated volumes is not physically possible.

Table 2 – Littoral and estimated submerged vegetation areas at the average stage for April through November 2010 calculated from observed lake stages and from stages estimated from model computations for the three scenarios.

Scenario	Stage, ft (MSL, 1912)	Lake Area, acres	Littoral Area, acres	Estimated Submerged Vegetation Area, acres
Observed	919.9	2,300	1,360	1,200
No use	923.4	2,430	1,300	1,110
Existing permits	920.9	2,370	1,380	1,200
Maximum	918.3	2,020	1,160	1,020

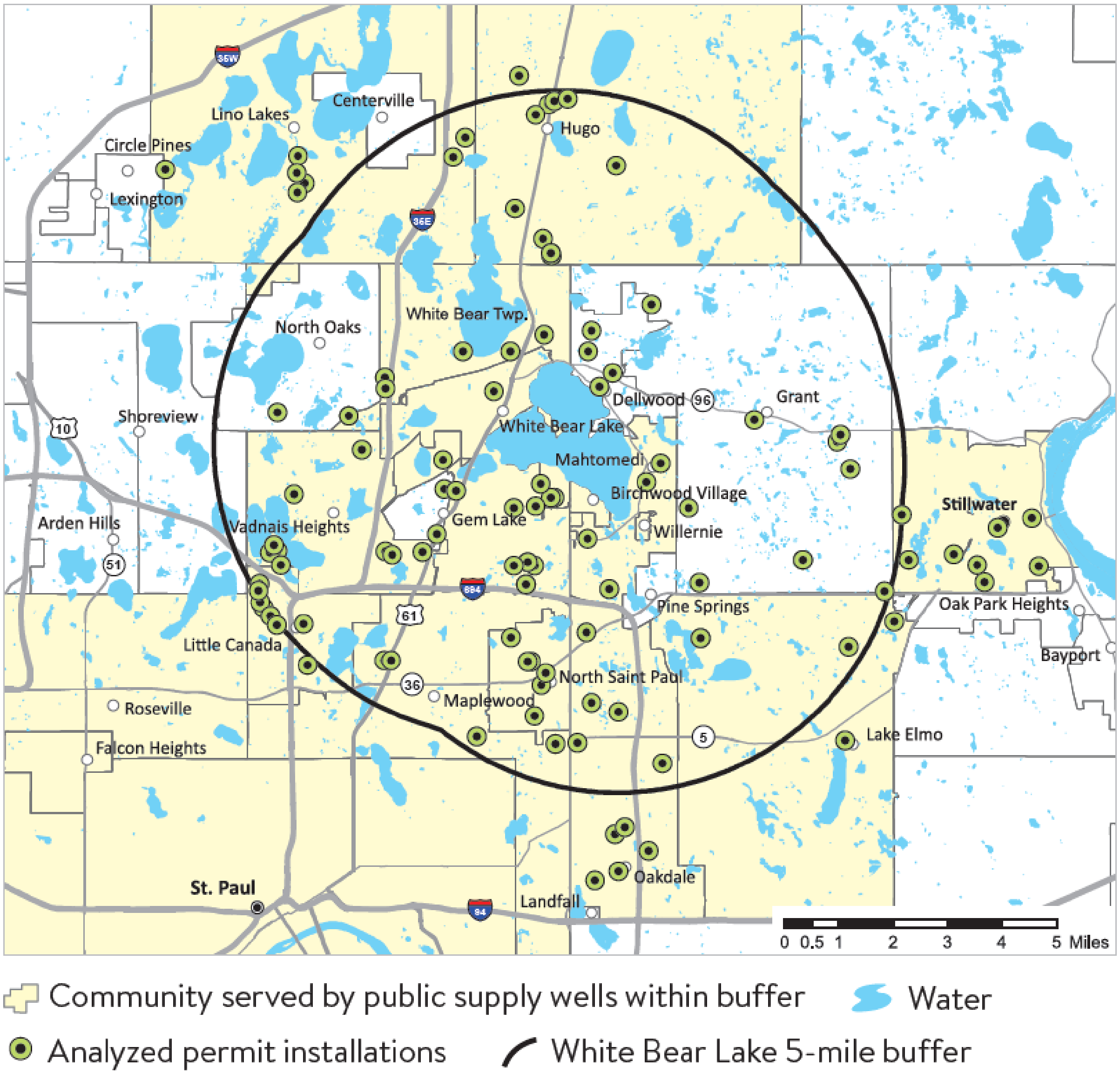


Figure 1 – Map showing WBL, a 5-mile buffer around WBL, and installations (wells, drains, etc.) associated with groundwater appropriation permits with at least one installation within 5 miles of WBL.

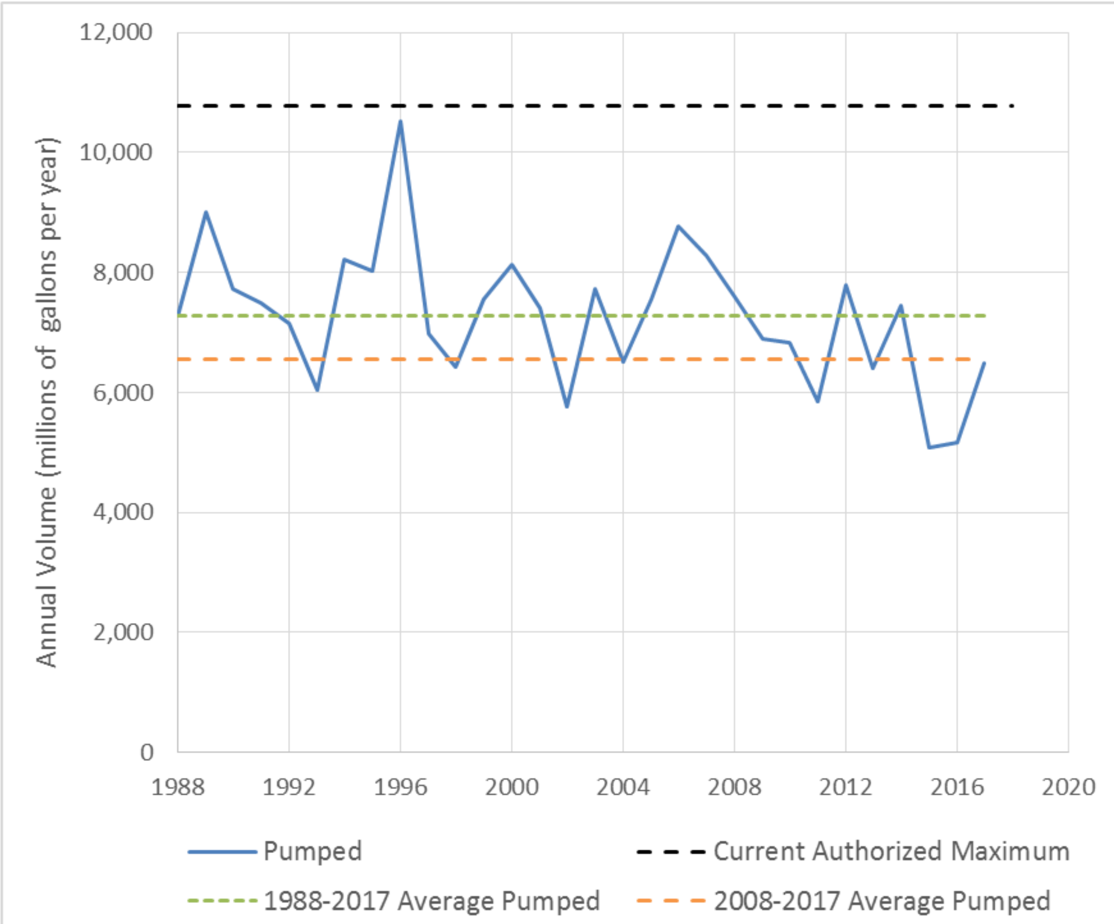
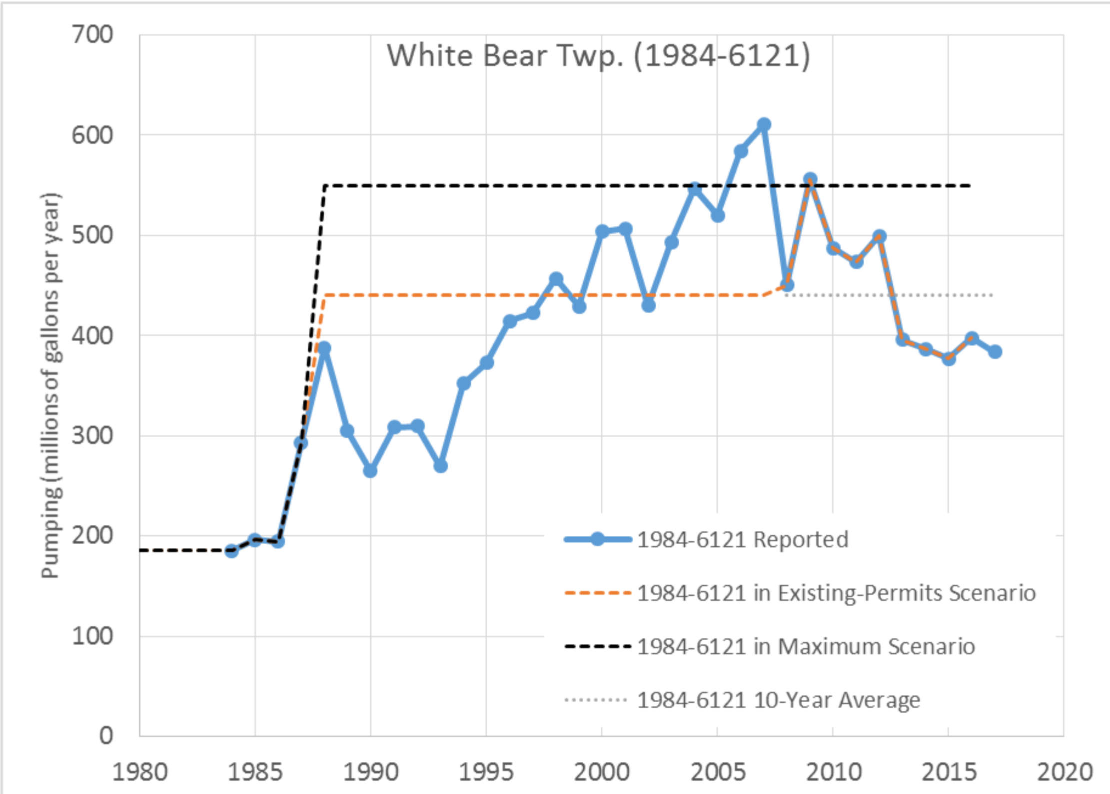


Figure 2 – Collective total, annual volumes from 1988 through 2017 for groundwater appropriation permits that pump groundwater within 5 miles of WBL (including wells that are outside of 5 miles but are part of a permit with at least one well inside the 5 mile area): pumped, current authorized maximum (i.e. *maximum* scenario), 1988-2017 average, and 2008-2017 average. Note that volume totals do not include the permit for gravity drainage (2006-0618) or former permits that were terminated.



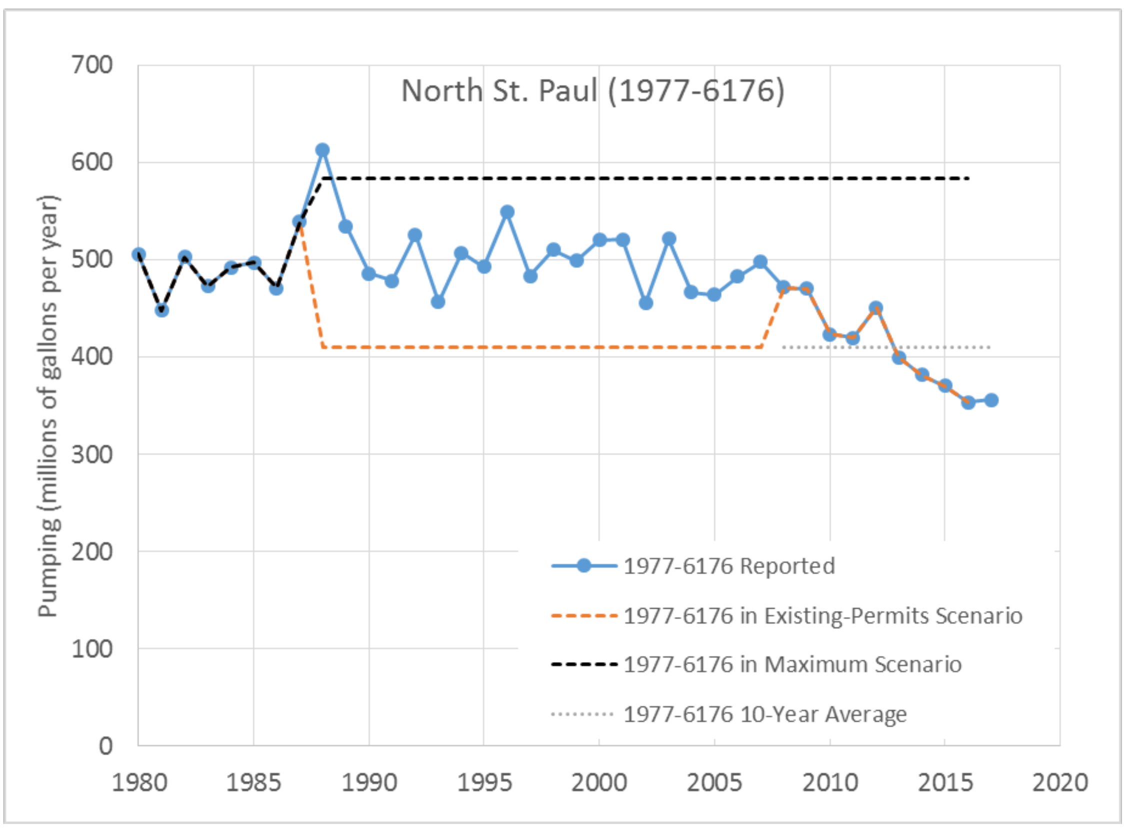


Figure 3 – Examples of adjustments made to reported annual volumes for two of the permits in the *existing permits* and *maximum* scenarios.

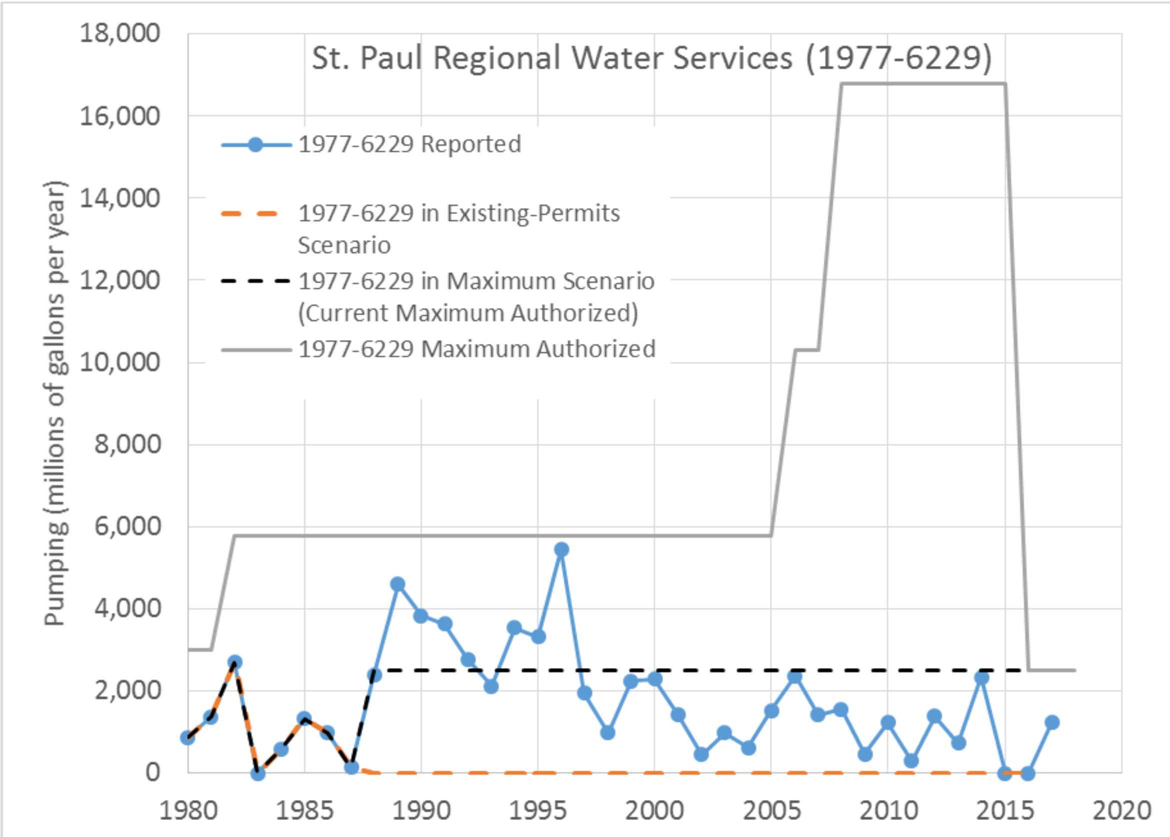


Figure 4 – Annual groundwater volumes for St. Paul Regional Water Services (SPRWS): actual reported, pumping in the *existing permits* and *maximum* scenarios, and maximum authorized over time. Note that starting in 2015, SPRWS will rarely appropriate groundwater, and pumping in 2017 was a special and unusual occurrence while the surface water supply was disrupted during a construction project.

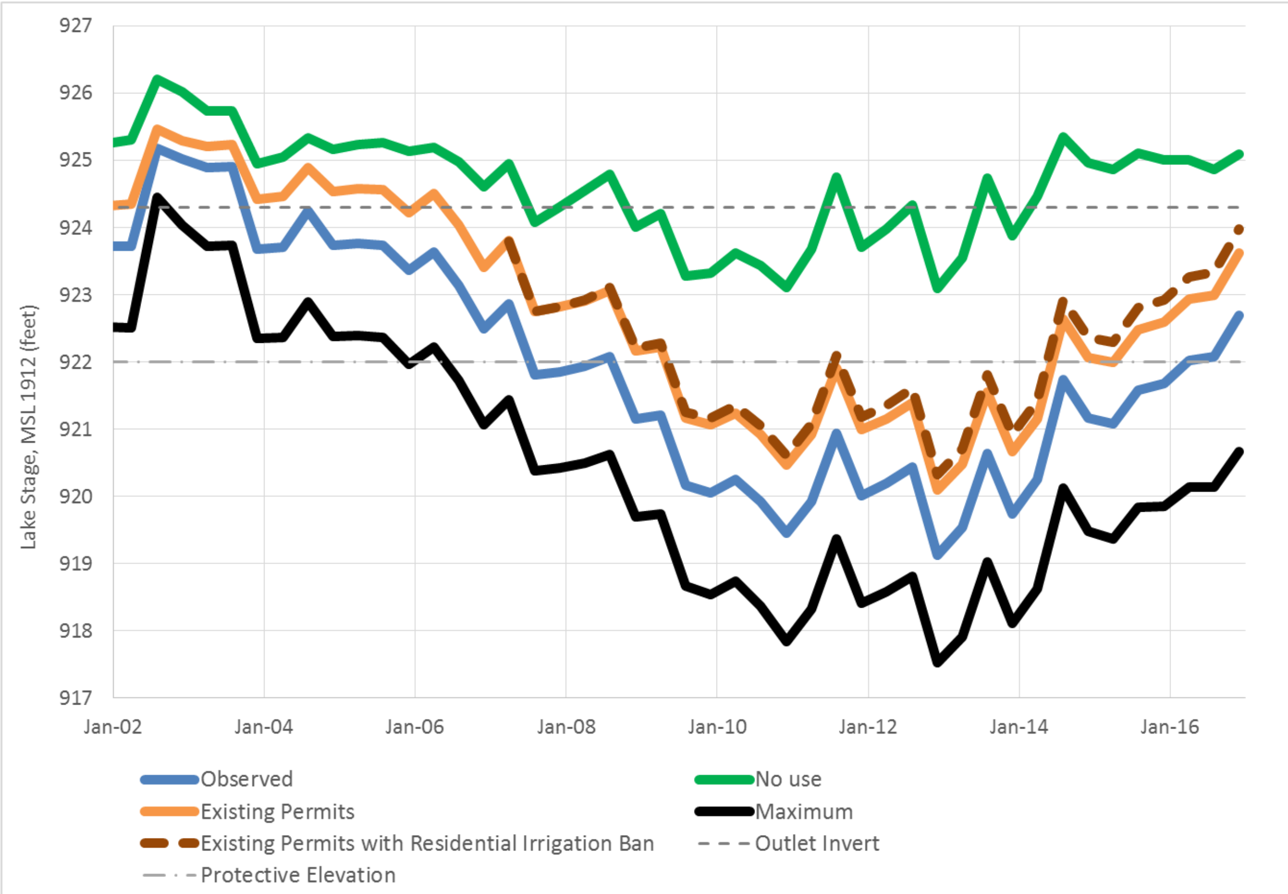


Figure 5 – Observed and calculated lake stages for triannual model scenarios

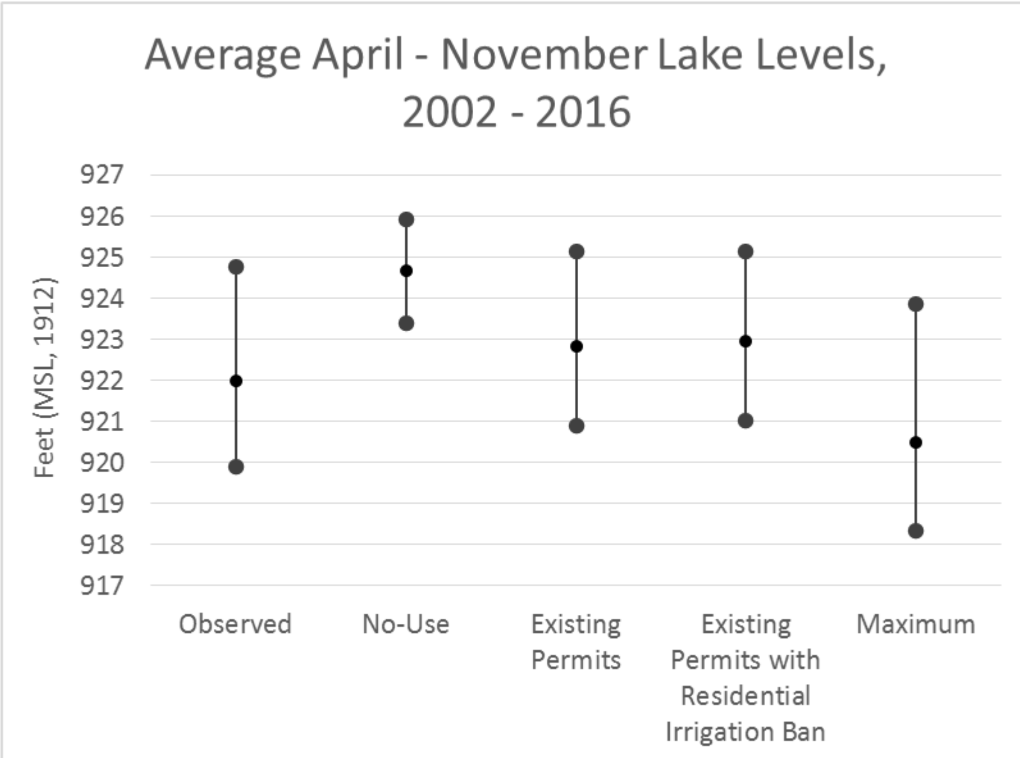


Figure 6 - Maximum, average and minimum (2002 through 2016) April through November averaged lake stages

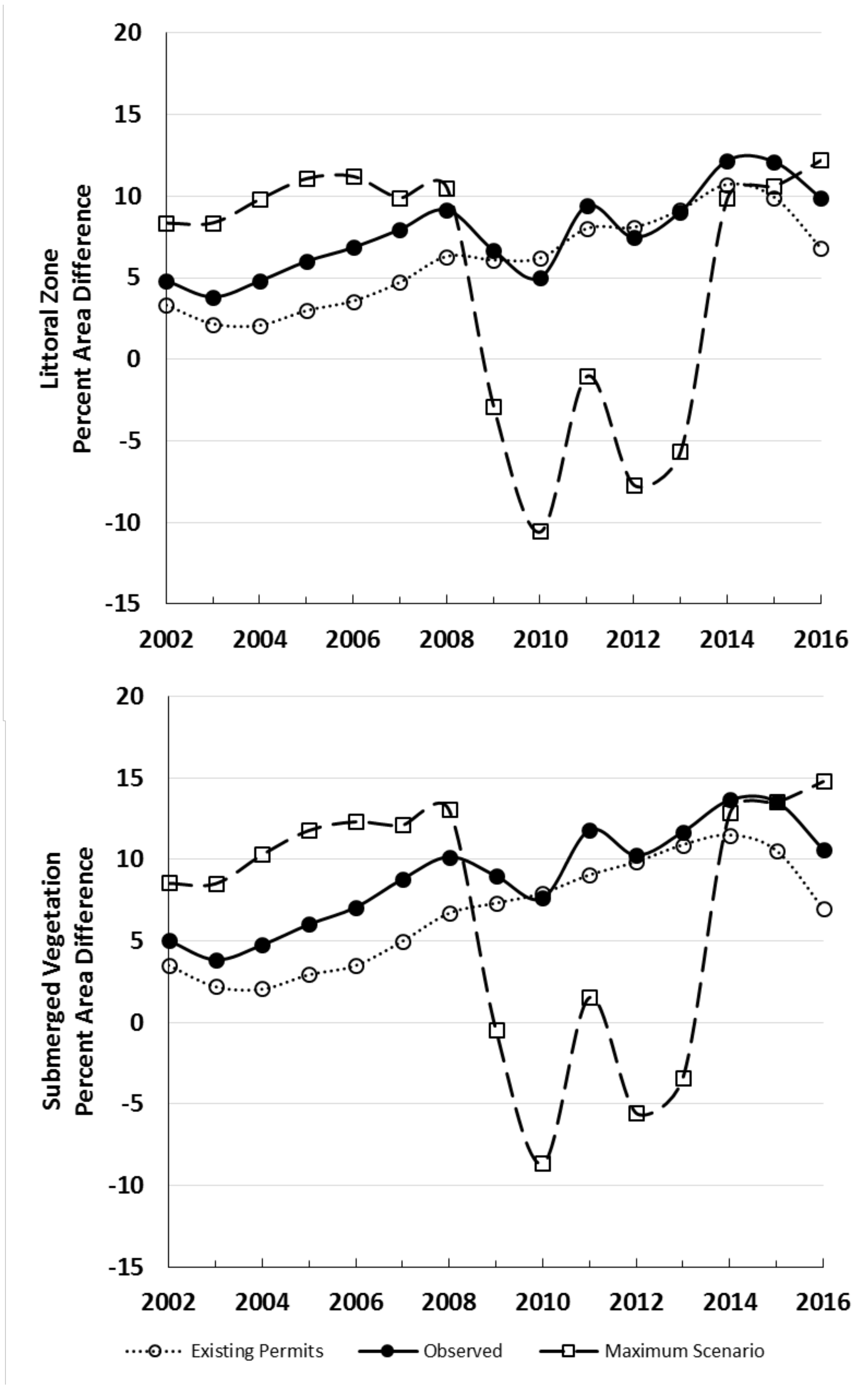


Figure 7 - Percent change in estimated littoral zone area (upper) and submerged vegetation area (lower) for the average, April through November stage in the *existing permits* scenario, observed lake stages, and *maximum* scenario from the reference, *no use* scenario.

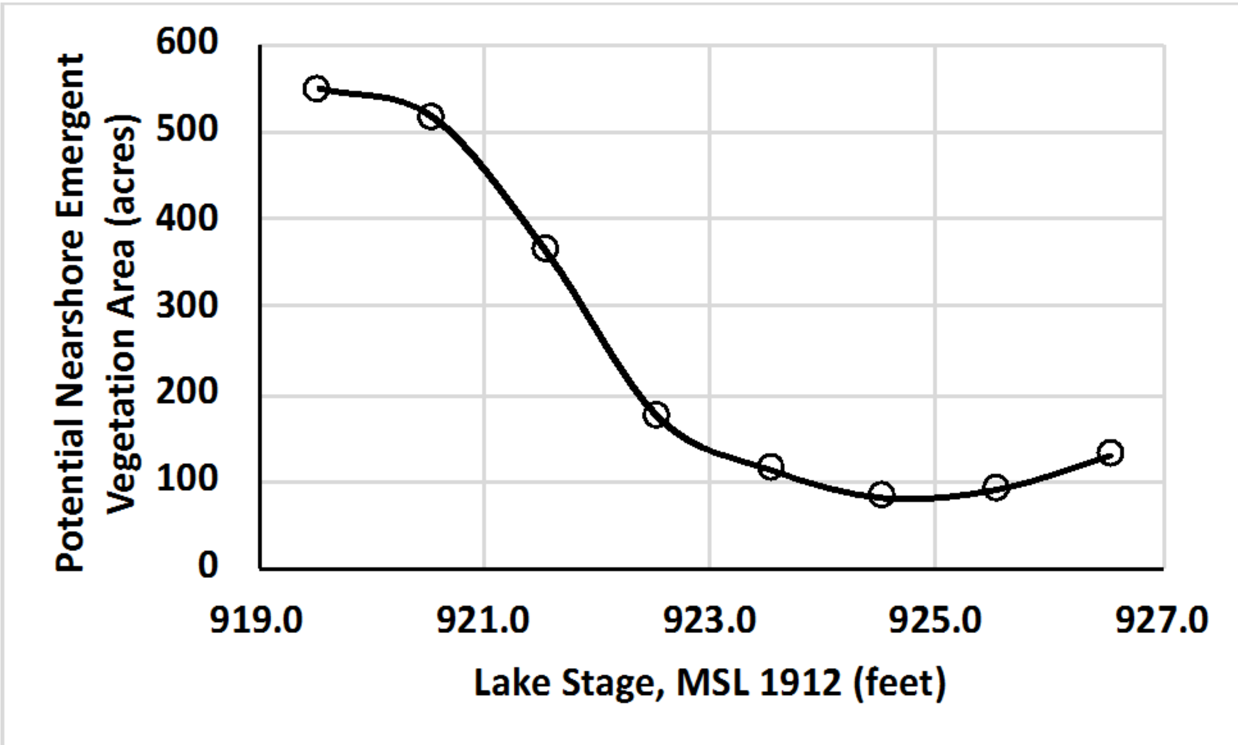


Figure 8 - The estimated potential nearshore emergent vegetation area at different stable water levels.

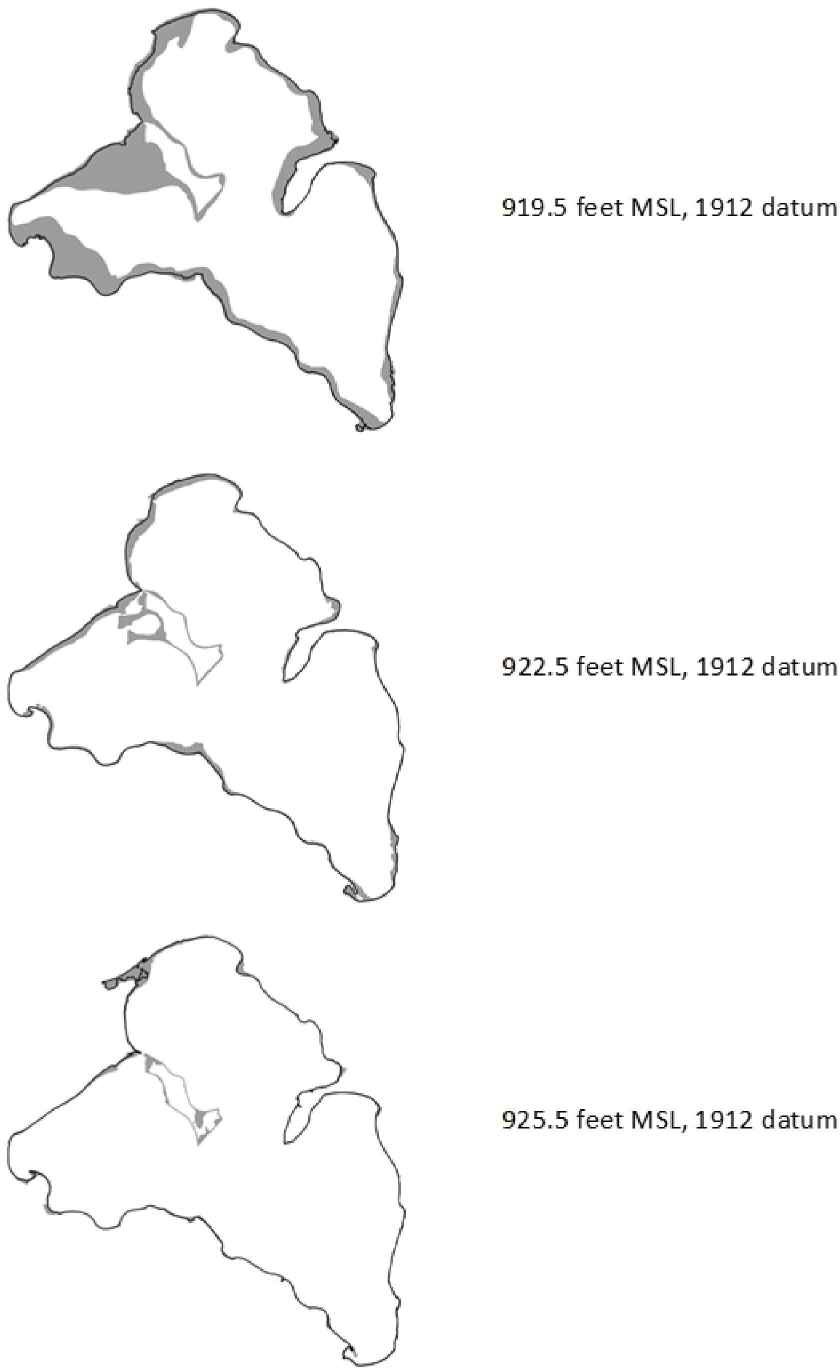


Figure 9 - The estimated potential nearshore emergent vegetation area at three different stable lake stages, 919.5, 922.5, and 925.5 feet MSL, 1912 datum.

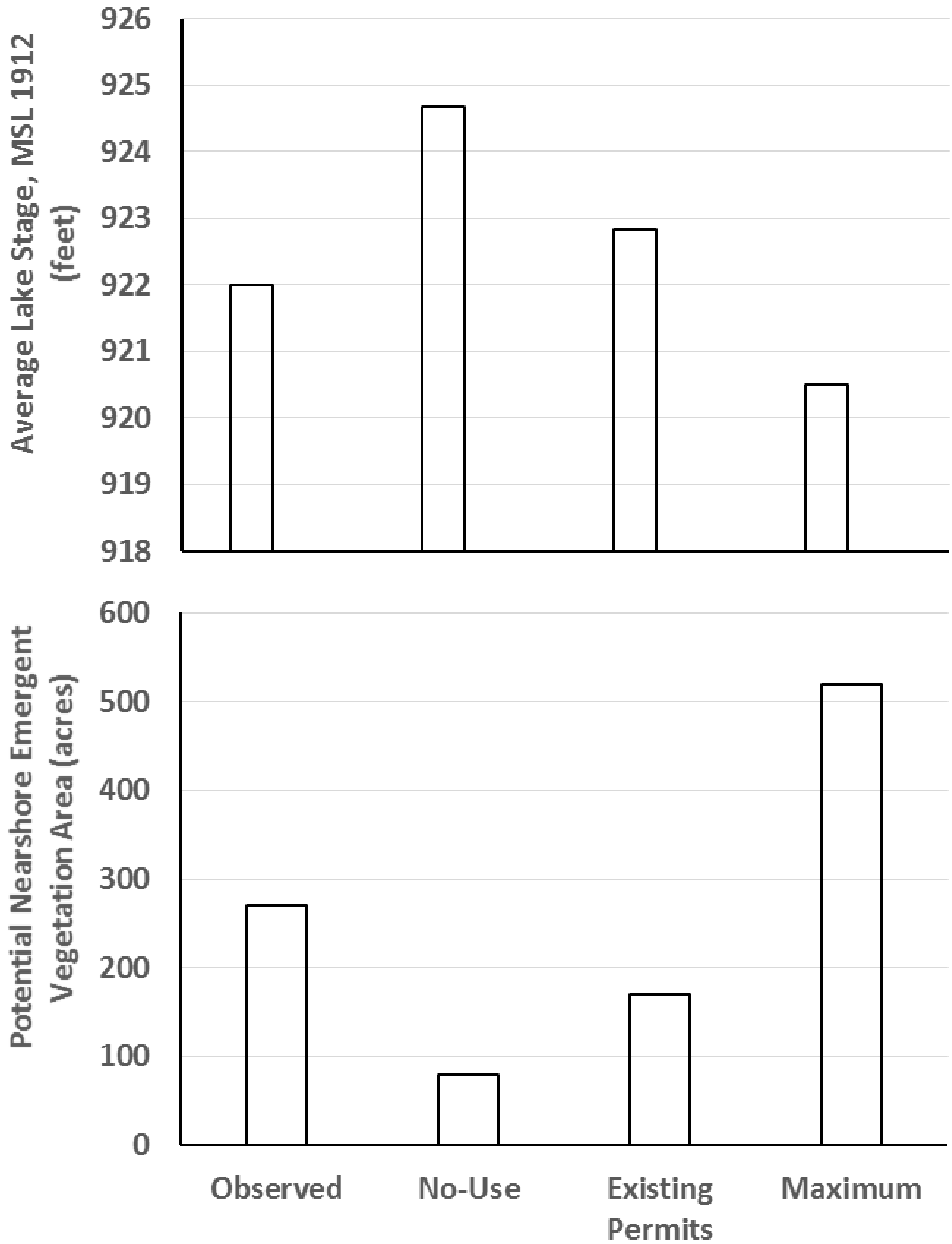
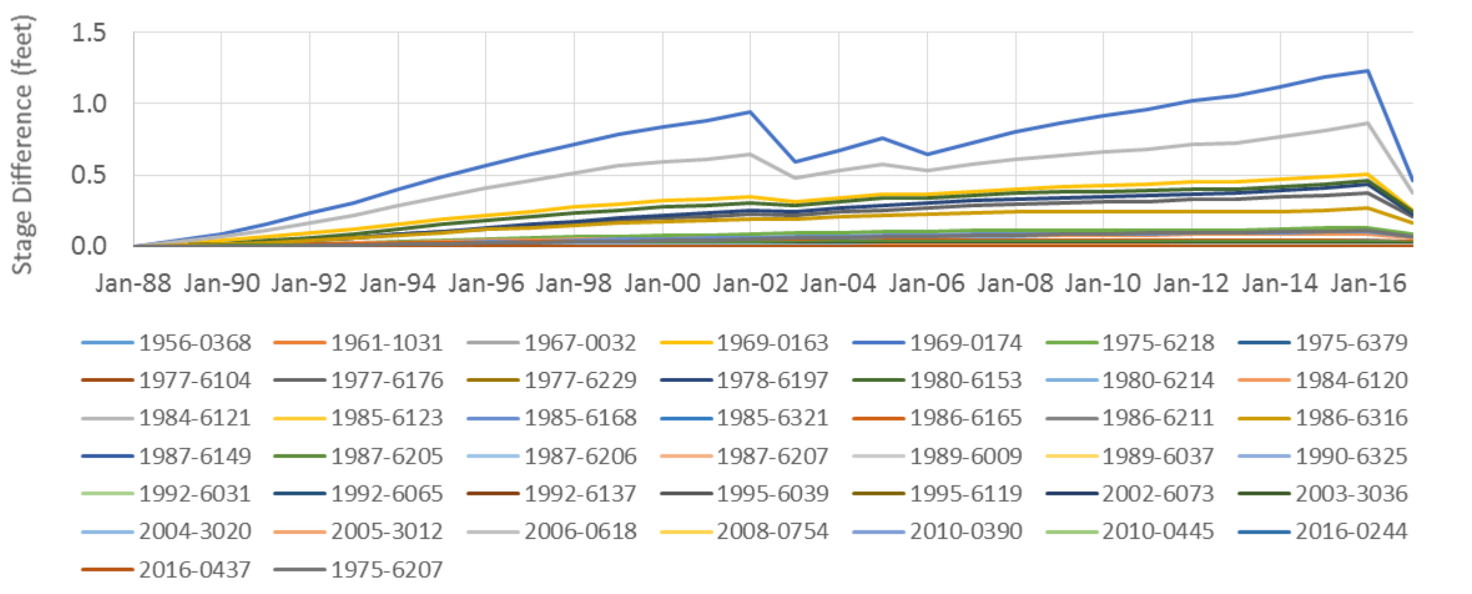


Figure 10 - The estimated 2002 through 2016, April through November average lake stage (upper) and the potential nearshore emergent vegetation area for observed, *no use* scenario, *existing permits* scenario, and *maximum* scenario.



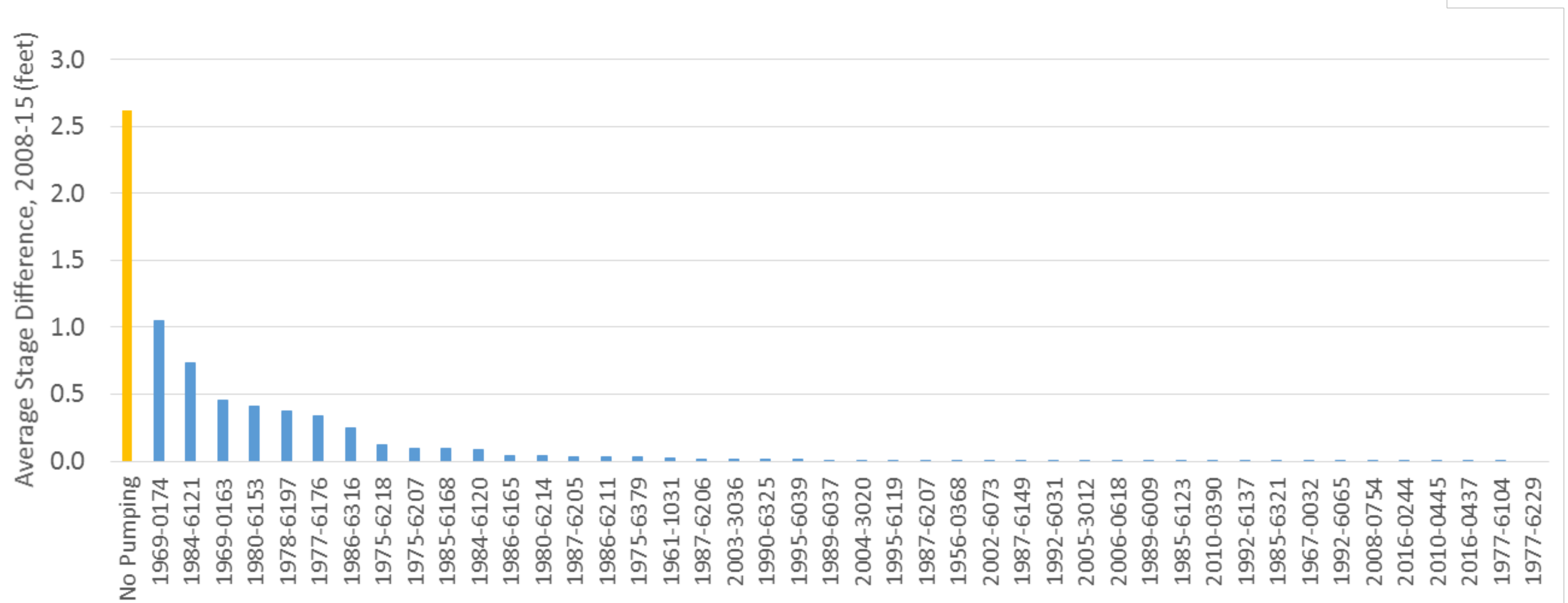


Figure 11 – Annual model computed stage differences (top) and averaged over 2008 through 2015 (bottom) for the individual permits analysis in the *existing permits* scenario.