HDR | ONE COMPANY *Many Solutions*℠

Memo

To:	Melissa Bokman and Paul Nelson, Scott County		
From:	/ST	Project:	Dean Lake Data Review
cc:			
Date:	January 9, 2014	Job No: 219491	

Re: Dean Lake Water Quality and Vegetation

INTRODUCTION

Scott County has partnered with the Lower Minnesota River Watershed District (LMRWD) to collect and analyze existing data for Dean Lake, Scott County (Lake ID#70-0074-00-451). Dean Lake is listed as an impaired water body of the State for aquatic recreation caused by excessive nutrients (eutrophication). It therefore requires a Total Maximum Daily Load (TMDL) study to describe its natural history as well as the current condition and sources of nutrient loading to the lake. Scott County contracted with HDR, Inc. (HDR) to begin the data collection phase of the TMDL study. This memorandum presents a review of the existing historical water quality and vegetation data available for Dean Lake.

HISTORICAL BACKGROUND

Dean Lake is a shallow, 122-acre lake (averaging 3 to 5 feet in depth) within the Lower Minnesota River Major Watershed in the municipality of Shakopee, Scott County, MN. It resides on top of an older Minnesota River floodplain terrace, well above the active floodplain. It is part of the North Central Hardwood Forest Ecoregion, Minnesota and Northeast Iowa Morainal Section, and Big Woods Subsection. The landscape position serves as an ecotone between semiarid areas historically dominated by prairies and semi-humid mixed conifer-decidous forest to its northeast. Its western boundary served as a transition from forests and woodlands to open grasslands while its northeastern extent transitioned to mixed conifer-hardwood dominated systems (MNDNR, 2005). Historic land surveys (1895) suggest the watershed draining to Dean Lake was predominantly prairie before major landcover alterations began (MNDNR-MIS Bureau, 1994). Glacial processes of the Pleistocene shaped the landscape through glacial drift deposition and glacial meltwater formation of the Minnesota River and its terraces, wetlands and floodplain. Surface drift is of Wisconsin Age and predominantly calcareous. In this part of Minnesota, precipitation roughly equals evapotranspiration in undisturbed habitats (MNDNR, 2005). It is likely that Dean Lake's watershed began to be transformed from its natural state to agriculture some time between 1850 and the 1890 as the Minnesotans colonized this portion of Scott County (Scott County, 2008).

At least two studies and ten years of water quality sampling have been performed relevant to Dean Lake in the past. In 1975, the LMRWD published a study of source water contributions to Dean Lake that also analyzed potential hazards to the Lake associated with various development considerations (Samstad, 1975). The report cites a "Water Resources Inventory of the Lower Minnesota River Watershed District" describing the lake as 216 acres with an estimated maximum depth of 5 feet (3 feet on average) with its water supply coming from seepage, natural springs and intermittent surface drainage from terraces and bluffs. It describes one intermittent unnamed creek inlet to the Lake's southeast. That same LMRWD report describes the lake as a perched system indicative of the local ground water table.

Samstad's (1975) description of the relationships of Dean Lake to the nearby terraces, soil relationships and bedrock condition suggested a slight revision to a previously expounded perched lake theory. In short, soil boring results indicate that ground water percolating from the higher elevation terraces work through fractured dolomite and alluvium until coming into contact with sloping bedrock formations. The groundwater then daylights within the alluvial depression that defines the lake bathymetry. In contrast to previous theory, no subsurface upwelling of bedrock limits Dean Lake's groundwater source from moving towards the Minnesota River. In 1975, no permanent outlet to the lake was identified; however, an intermittent outlet carried flows north, then east. The report suggests that the main movement of water out of Dean Lake was via groundwater.

A 1980 study performed by the City of Shakopee served as a feasibility study of drainage alternatives for Dean Lake's surface outlet (City of Shakopee, 1980). At the time of the 1980 study, the upstream Prior Lake Outlet channel was still conceptual and much of the Lake's hydrology remained unchanged since the 1975 report (above). The study presented several outlet design alternatives for the Lake as well as provided a historic record of existing conditions that are useful in considering the natural history of the lake. The study also considers Dean Lake as either a Type 3 or Type 4 wetland ("inland shallow fresh marsh" to an "inland deep fresh marsh") with an average depth of only 1 to 2 feet. A report by the Minnesota Department of Natural Resources (MNDNR), mentioned in the 1980 City of Shakopee study, recorded water level fluctuations of up to 5 feet with an overflow elevation at 747.0 feet above sea level. Normal elevations for the lake in the mid-1970's were considered to be between 745.0-746.0 feet.

Prior Lake's outlet channel was connected to Dean Lake in 1982 (PLSLWD, 1983). Dean Lake developed an average water elevation of approximately 747.0 feet shortly thereafter (Figure 1). The Prior Lake-Spring Lake Watershed District (PLSLWD) set Dean Lake's outlet elevation at 746.0 feet in 2005 for their XPSWMM watershed model citing the City of Shakopee's outlet structure project (City of Shakopee, 2005) and a survey in April 2012 by EOR Engineering, Inc. (personal communication with Carl Almer).

WATER QUALITY – PAST AND PRESENT

The earliest known record for water quality in Dean Lake is found within the 1980 study (City of Shakopee, 1980). At that time, the water quality in Dean Lake was sampled once with 40 parts per million (ppm) sulfate, total alkalinity of 95 ppm and a total phosphorous (TP) concentration of 52 parts per billion (ppb). That reported estimated watershed loading to the Lake to be 300 pounds per year from mainly agricultural lands, open space and some limited residential development. The report suggested that if the Prior Lake outlet channel was established at a sustained 25 cubic feet per second (cfs) discharge for an extended period, the entire volume of Dean Lake would be exchanged on a period of approximately 3 to 4 days if complete mixing were to occur. Although it was beyond the scope of the study to estimate the water quality effects of this scenario, it did suggest that, given the Lake's small size to such an increased drainage area brought on through a Prior Lake outlet channel connection, the quality of water in the Lake would likely take on that of the inflowing water.

The University of Minnesota's Remote Sensing Lab analyzed aerial photography dating back to 1975 to estimate water clarity (Table 1. Historic water clarity (UMNRSL, 2013); UMNRSL, 2013). Water clarity is affected by the concentration of chlorophyll-a (chl-a) as algae density proliferates in response to increases in nutrient richness. The remote sensing data predicted a water clarity range from 0-1.87 m for the period 1975-2008 (*n*=7; 0.96m avg.; Table 1). It should be noted that the shallow depth of the lake likely limits secchi depth results in some years.

The Metropolitan Council Environmental Services (MCES) employed its Citizen-Assisted Lake Monitoring Program to collect water quality data from 2002 to 2011 (MPCA 2013a; Table 2). For the data collection period, secchi depths ranged from less than 0.5 meters to more than three meters (Figure 2). A comparison of annual clarity appears similar between 2002 and 2007 with 2008 and 2010 being clearer than most preceding years (Figure 3). Annual chl-a concentrations ranged from 1 µg/L to 300 µg/L during the sampling period (Figure 4) with dramatic differences between magnitude of concentration spiking likely causing annual averages to be similar (Figure 5). Total phosphorus concentrations ranged from 0.06 mg/L to 0.91 mg/L (Figure 6) with significant differences detected between various years (Table 3).

Analysis of this data suggests that Dean Lake's Trophic State Index (TSI), a number summarizing a lake's overall expected nutrient richness, or eutrophication level, for chl-a is 67 (out of 80) and TP to be 86 (beyond the limits for standard graphic reporting). The expected TSI ranges for lakes within Dean Lake's region are 46 to 61 for chl-a and 49 to 61 for TP. (MPCA 2013b). The 10-yr averages for chl-a and TP are reported as 42 ppb and 292 ppb, respectively. The MCES data place Dean Lake within the eutrophic to hypereutrophic ranges suggesting nutrient rich conditions. These conditions support abundant macrophyte and algae populations and thus frequently are assigned impaired in relation to aquatic use, as is the case for Dean Lake.

The PLSLWD maintains and outlet at Prior Lake that discharges to an outlet channel that drains to Dean Lake. Each year the PLSLWD provides a Prior Lake Outlet System Annual Operations Report to the Department of Natural Resources. In the most recent report, dated February 19, 2013, the report presents a summary of volume of water discharged from Prior Lake to-date (PLSLWD, 2013). To investigate potential for correlative relationships between Prior Lake's discharge and water quality within Dean Lake, a scatter plot and regression of these data to in-lake data was performed (Figure 8). No clear correlation was found between flow and TP concentrations within Dean Lake for the nine years of temporally related data. In two years (2009 and 2004) with 0.00 cfs to 13.00 cfs of average annual flow recorded by the PLSWLD, Dean Lake had 0.543 mg/L and 0.113 mg/L of TP, respectively. For the remaining years, the regression line's slope was nearly flat. The average flow for these remaining years was 4224.14 ac-ft (s.d. 2970.30) and the average TP concentration in Dean Lake was 0.242 mg/L (s.d. 0.075 mg/L). These results suggest that for these nine years (2002-2010) the Prior Lake effluent had no apparently profound impact on in-lake concentrations of TP for Dean Lake. Some combination of watershed loading to both the channel and the lake teamed with internal loading appears to control water quality within Dean Lake.

Water quality data for the Prior Lake outlet channel was collected from 2009-2010 at seven locations between Prior and Dean Lakes and at two locations between Dean Lake and the Minnesota River (Figure 9). Several water quality parameters were measured along with flow information. At the closest sampling site upstream of Dean Lake, Site 29, measurements detected flow in one of 16 samples in 2009 (March 25-November 6) and 20 of 21 samples in 2010 (March 10-September 23)(Table 4). For these data, phosphorus and flow data within the channel was collected concurrently on nine dates from early spring through September (Figure 10). Although more continuous sampling of these parameters is preferred for calibration of water quality and flow models of the channel, the data may prove useful for initial efforts. Similarly, the relationship between channel water quality and flow to in-lake conditions can be described provided significant overlap in temporal water quality data. In the case of Dean Lake-Prior Lake Outlet Channel TP data, the 2010 sampling year provides such potential insight (Figure 11and Figure 12*). However, same-day sampling only occurred on one day with gaps between l*ake and channel data ranging from five to 26 days.

VEGETATION DISTRIBUTION AND ABUNDANCE – PAST AND PRESENT

The composition and extent of transitional, emergent and submerged vegetative communities has changed through time. A review of historic aerial photographs and literature, as well as a survey of both submerged and emergent vegetation, provides a 56-year snapshot of how vegetation and open-water extent has changed through time. Scott County Geographic Information Systems (GIS) department provided spatially rectified aerial imagery that allowed delineation of the emergent vegetation-open water interface though time (1937-2010; Figure 13). In 1937, Dean Lake appears to have no open water conditions with the likelihood of a fresh meadow/scrub-shrub swamp complex remaining during the dust bowl era. Similarly, the 1980 aerials show little to no open water. The remaining years on Scott County aerial imagery record had open water ranging from 31 to 114 acres (average of 76 acres). In the latest imagery, 2010, open water comprised approximately 91 acres, essentially unchanged from 2000.

A submerged aquatic vegetation survey was conducted on September 13, 2013 by Bluewater Science (McComas and Stuckert, 2013;Figure 14). A healthy abundance, distribution and diversity of native plant species were detected by common point-intercept methods at 43 sites. Coontail, Star Duckweed and Elodea dominated the communities (Table 5). As with the areal distribution of species, Coontail, Star Duckweed and Elodea were most prevalent in the vertical distribution of species assemblage, dominating the 3 foot depth (Table 6).

The overall aquatic plant assemblage within the Lake is dominated by a diverse array of native species with high abundance with no invasive species noted. The fact that there is no easy public access to the lake has likely helped in the preservation of a healthy native submergent plant assemblage. High-density stands of submerged vegetation are common to lakes with eutrophic conditions. The reported densities may also suggest that carp and bullheads are likely not present in significant numbers to uproot plants.

This raises questions as to why carp may not be selecting Dean Lake for habitat needs as they are present in abundance both up and downstream of the Lake. A review of the Carp Habitat Suitability Index Model (Edwards and Twomey, 1982) provides a base set of information regarding carp habitat selection. Adult Carp feed on any available food source, typically, while fry initially feed on zooplankton, switching to phytoplankton when zooplankton densities are low. Juveniles switch feeding behavior to littoral fauna and the benthic fauna (worms, larvae) as well as plant materials (seeds, algae, detritus). Carp spawn in spring (May to June) with access to flooded terrestrial vegetation or submerged plants from <0.5 m to 1.8 m providing good structure Some studies suggest that fluctuating water levels may be detrimental to carp populations. For overall habitat preferences, Carp prefer enriched, shallow, warm, sluggish and well-vegetated waters with mud or silt substrates. A lake's reservoir storage ratio (mean annual reservoir water volume to annual discharge volume) can affect carp populations with a peak at low and mid ratios (< 0.4 and 1.5) and decline at higher ratios (>2.0). Carp are tolerant of turbidity until a point where it affects food availability and optimal growth occurs within pH levels of 6.8-8.7 (detrimental at <6.0 given correlated reduction in food supply and lethal above 10.5). The number of days with temperatures >20°C affects production (warmer temperatures preferred) with negative impacts to populations at <13°C and ≥30°C. Correlative to temperature, Carp are very tolerant to low dissolved oxygen (DO) and can gulp atmospheric air when the DO is ≤0.5 mg/L while ranges of 6 mg/L to 7 mg/L promote growth.

Although Carp are found within the Prior Lake-Spring Lake chain and in the downstream Minnesota River and floodplain lakes, it is likely that if they use Dean Lake, it is only for the limited spring period of spawning provided no fish passage barriers prohibit migration (e.g., no flow in the channel to prove fish passage). The Lake likely freezes most winters and the dry/frozen channel becomes a fish barrier to migration during this time. The period of spring spawning overlaps a period when native submerged plants are not abundant and, thus, would not be significantly impacted if the carp move back up or down channel before submerged native plants emerge. A spring survey of both submerged vegetation and presence/absence of carp would be highly informative not only for describing Dean Lake ecology, but for invasive species control planning efforts.

A relative survey of emergent vegetation was also conducted describing a distribution of mostly un-mixed species surrounding the lake (Figure 15). Cattails interfaced with the open water, in 2013, followed by Reed Canarygrass (*Phalaris arundinancea*) in shallow submerged through transitional zones. Patches of invasive Common Reedgrass (*Phragmites spp.*) were also mapped. Visual extrapolation of the color signatures of the species defined in the sample plots as well as information gleaned from field observations suggest an overwhelming dominance of these non-native species throughout the emergent and transitional zone.

TABLES AND FIGURES

Table 1. Historic water clarity (UMNRSL, 2013)

Year	Water Clarity (m)
1975	0.00
1985	1.87
1990	1.41
1995	0.67
2000	0.46
2005	0.86
2008	1.44

Table 2. Metropolitan Council Environmental Services Citizen-Assisted Lake Monitoring Program data for Dean lake, 2002-2011

Parameter	*n*	MIN	AVG	MAX
Chlorophyll a, corrected for pheophytin (µg/L)	72	1.00	34.48	300.00
Chlorophyll a, uncorrected for pheophytin (µg/L)	72	1.10	40.23	310.00
Chlorophyll b(µg/L)	46	1.00	5.00	23.00
Chlorophyll c(µg/L)	46	1.00	5.29	22.00
Chlorophyll/Pheophytin ratio (unitless)	30	1.08	1.35	1.65
Cloud cover (%)	62	0.00	40.32	100.00
Depth, Secchi disk depth (m)	65	0.15	0.84	3.10
Gage height (ft)	12	0.10	4.40	5.10
Kjeldahl nitrogen (mg/L)	77	0.82	2.64	11.00
Lake physical appearance (choice list)	74			
Lake recreational suitability (choice list)	71			
Pheophytin a (µg/L)	72	1.00	14.19	380.00
Phosphorus as P (mg/L)	77	0.03	0.23	0.91
Temperature, water (C)	74	7.00	23.62	33.00

Table 3. Comparison of differences in total phosphorus for Dean Lake between years (ANOVA, P-values; bold values illustrate significant differences detected at P=0.05)

P-value	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*
2002	0.231	0.405	0.470	**0.015**	**0.006**	0.448	**0.000**	0.429
2003		0.169	0.581	0.288	0.416	0.953	**0.015**	0.437
2004			0.251	**0.020**	**0.007**	0.385	**0.001**	0.157
2005				0.083	0.089	0.684	**0.002**	0.859
2006					0.565	0.490	0.100	**0.042**
2007						0.679	**0.023**	**0.021**
2008							0.052	0.620
2009								**0.001**
2010								

Table 4. Prior Lake-Spring Lake Watershed District Site 29 monitoring data, 2009-2010

Parameter	*n*	MIN	AVE	MAX
Calculated Flow (cfs)	36	0.00	1.05	7.68
Flow (cfs)	6	0.40	0.84	1.70
Dissolved Oxygen (mg/L)	26	4.86	9.63	18.86
pH	17	7.60	7.92	8.63
Temperature (C)	26	0.23	12.10	25.90
Conductivity (µS/cm))	26	430.00	546.13	660.00
Soluble Reactive Phosphorus (mg/L)	9	0.03	0.08	0.14
Total Phosphorus (mg/L)	9	0.06	0.12	0.19
FNU's	26	0.20	14.50	137.30
Chlorophyll-a (mg/m3)	9	2.90	7.50	16.00
Chloride (mg/L)	9	42.00	56.22	71.00
Total Suspended Solids (mg/L)	9	4.00	8.84	22.00
NOX (mg/L)	9	0.62	0.87	1.10

Table 5. Aquatic plant occurrence and density in Dean Lake, September 13, 2013 (McComas and Stuckert, 2013; point-intercept, rake method)

	Cat-tails	Duck-weed	Water-meal	Coon-tail	Curly-leaf Pond-weed	Elodea	Flatstem Pond-weed	Sago Pond-weed	Star Duck-weed	Stringy Pond-weed
Average Density	1.0	1.5	1.5	3.2	1.5	1.5	1.0	1.3	1.4	1.0
Occurrence (45 sites)	4	11	11	37	2	21	4	8	31	1
% Occurrence	9	26	26	86	5	49	9	19	72	2

Table 6. Occurrence of submerged plants by depth in Dean Lake to a depth of 5 feet

Depth (feet)	Number of Sites Sampled	Duck-weed	Water-meal	Coon-tail	Curly-leaf Pond-weed	Elodea	Flatstem Pond-weed	Sago Pond-weed	Star Duck-weed	Stringy Pond-weed
1	1	-	-	-	-	-	-	-	-	-
2	6	2	2	3	-	2	-	-	3	1
3	24	6	7	24	1	14	2	6	20	-
4	9	2	1	7	-	3	2	1	5	-
5	3	1	1	3	1	2	-	1	3	-
	43	11	11	37	2	21	4	8	31	1

Figure 1. Dean Lake water elevations, 1975-2013 (outlet structure established 1982)

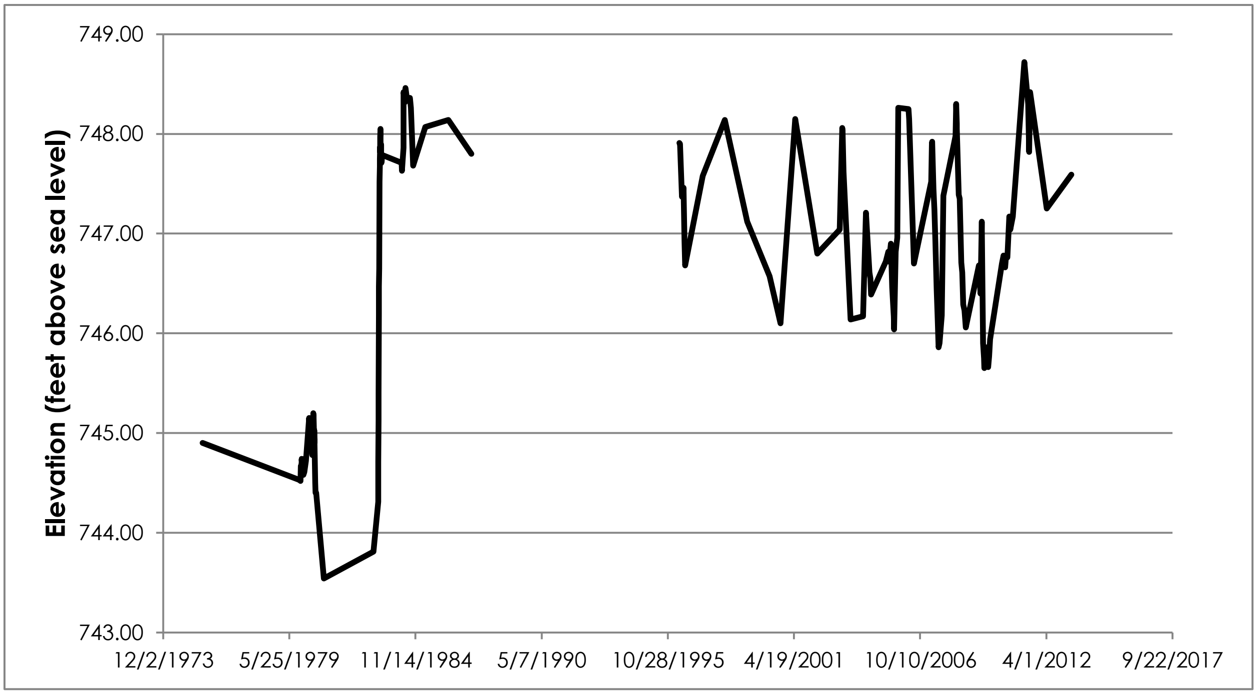


Figure 2. Secchi depth data for Dean Lake, 2002-2011 (blue line indicates the State standard)

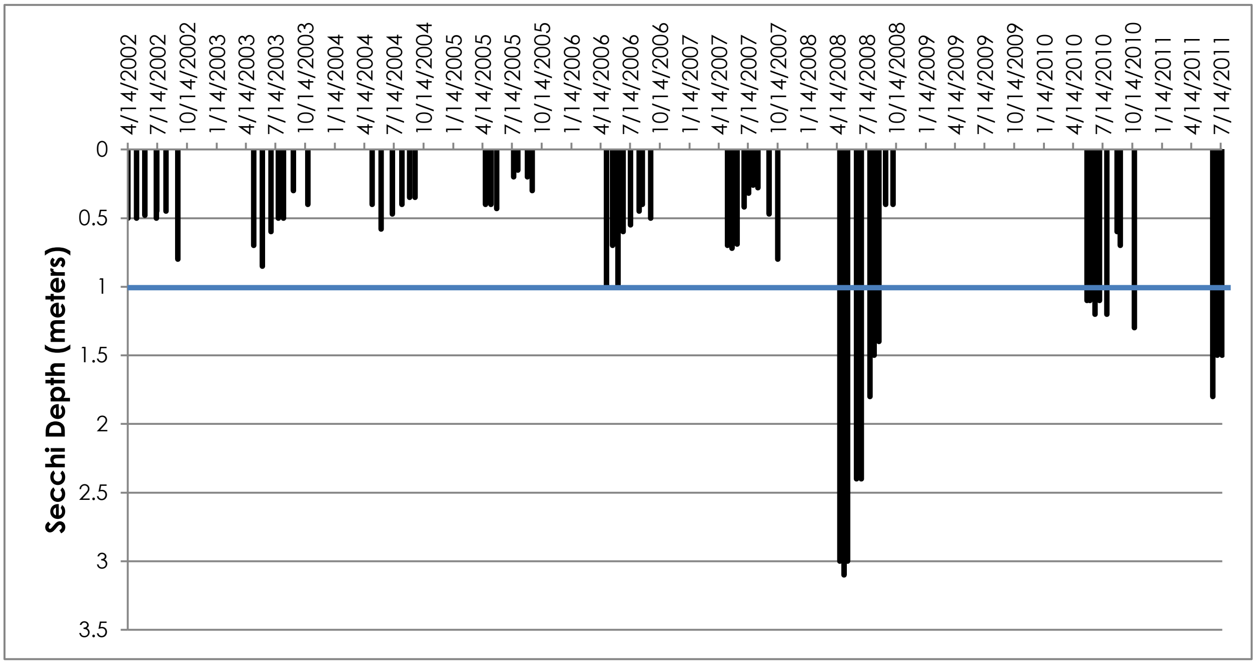


Figure 3. Median, 1st and 3rd quartiles, and 10th and 90th percentiles for Dean Lake secchi depth data, June 1through September 30 (insert: regression on means; no secchi data for 2009)

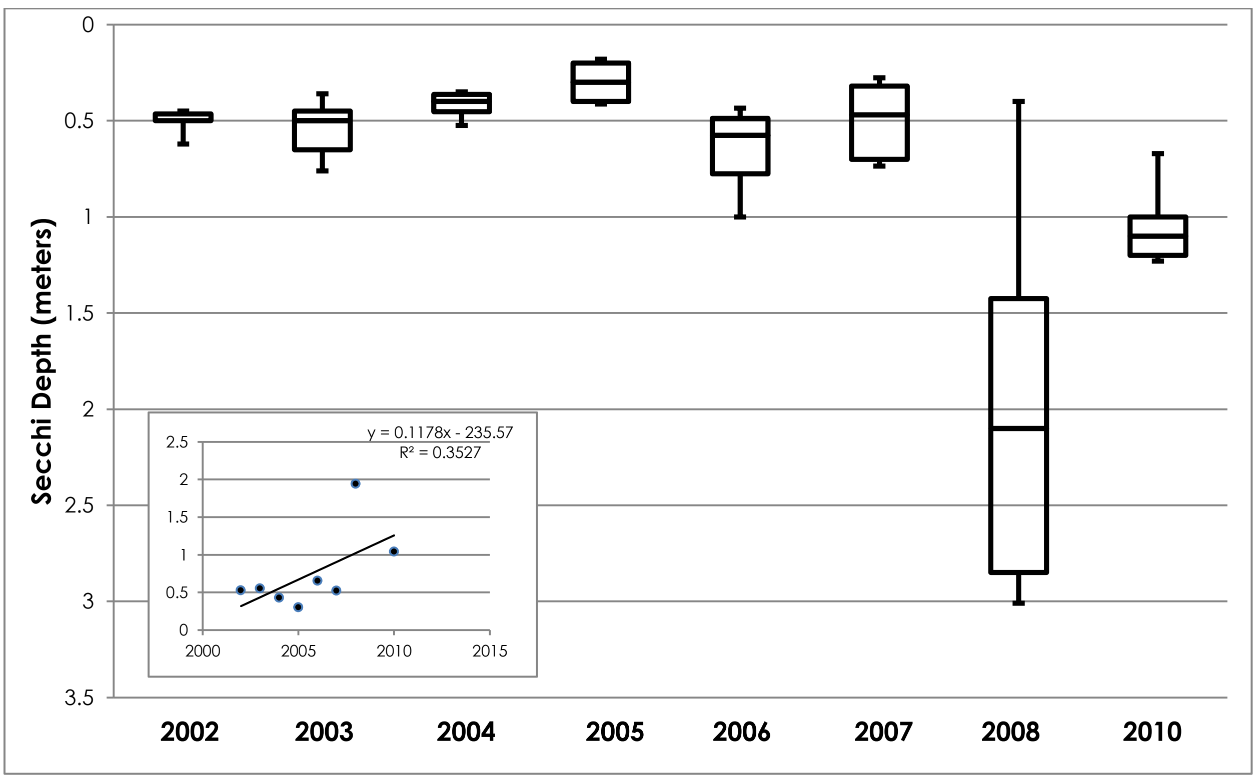


Figure 4. Chlorophyll-A, corrected for pheophytin, concentrations (µg/L) in Dean Lake (blue line indicates the State standard)

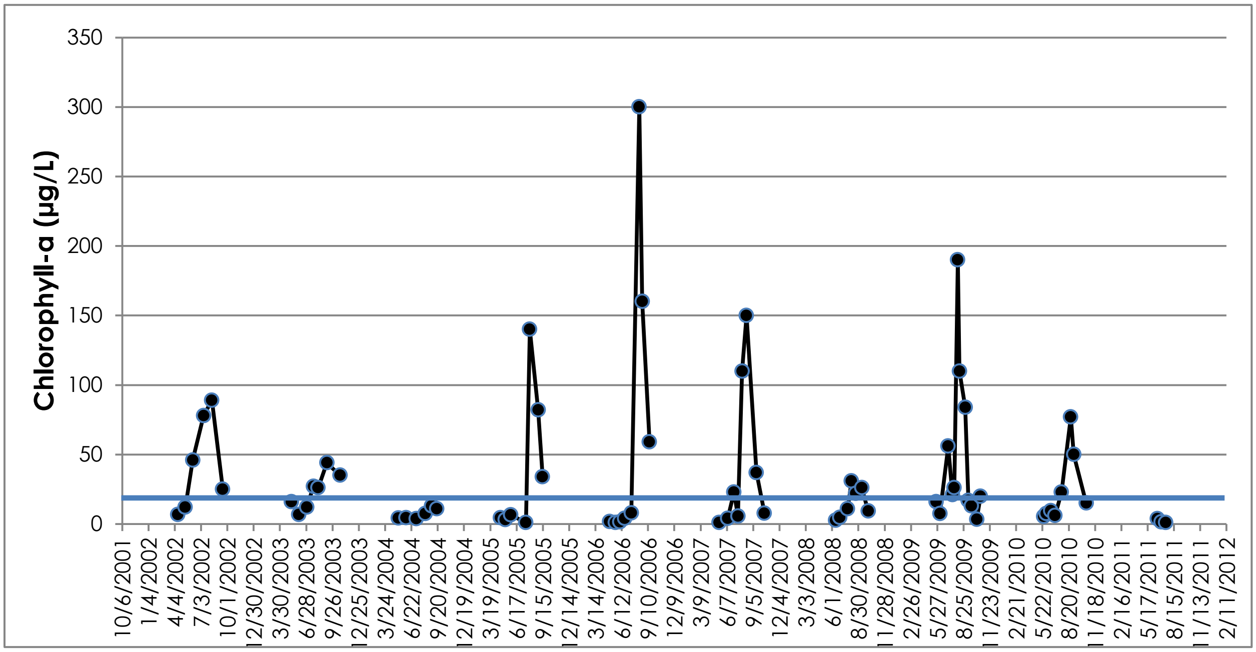


Figure 5. Median, 1st and 3rd quartiles, and 10th and 90th percentiles for various years of Dean Lake chlorophyll-a data, June 1through September 30 (insert: regression on means)

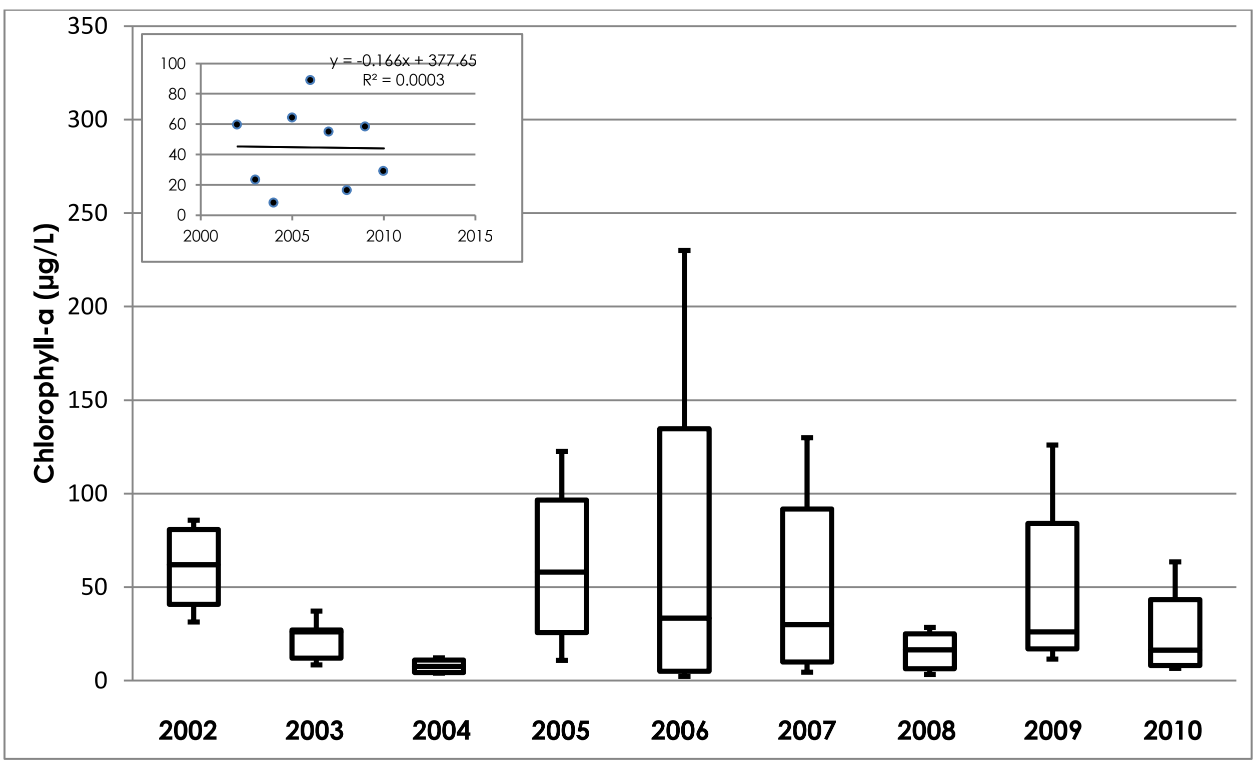


Figure 6. Dean Lake total phosphorus concentrations (mg/L), 2002-2012 (blue line indicates the State standard)

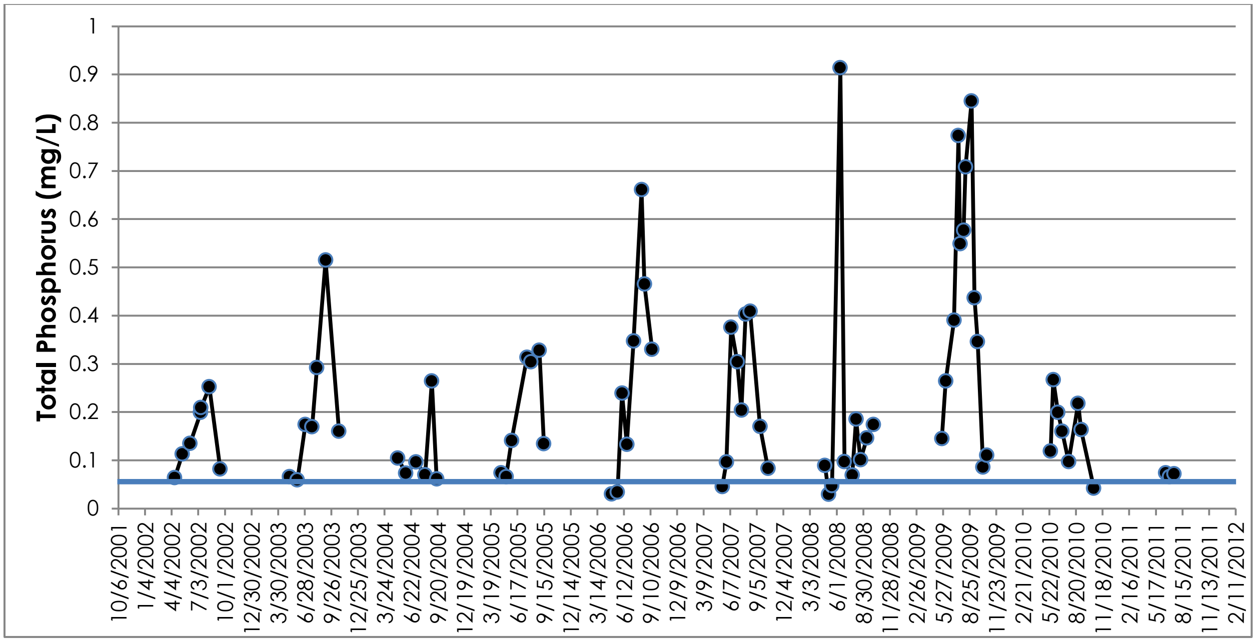
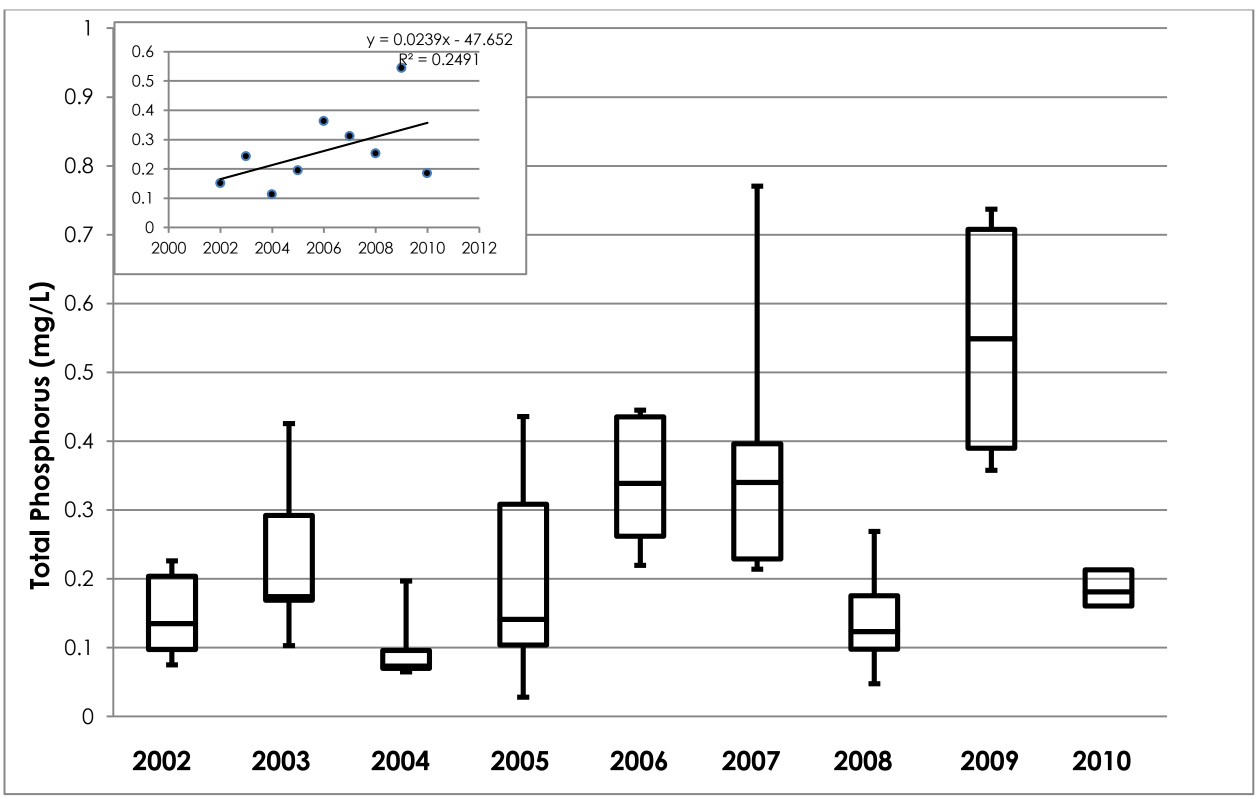


Figure 7. Median, 1st and 3rd quartiles, and 10th and 90th percentiles for various years of Dean Lake phosphorus data, June 1through September 30 (insert: regression on means)



701 Xenia Avenue South, Suite 600
Minneapolis, MN 55416

Phone (763) 591-5400
Fax (763) 591-5413
www.hdrinc.com

Figure 8. Relationship between Prior Lake outlet channel discharge and Dean Lake annual, average TP concentration.

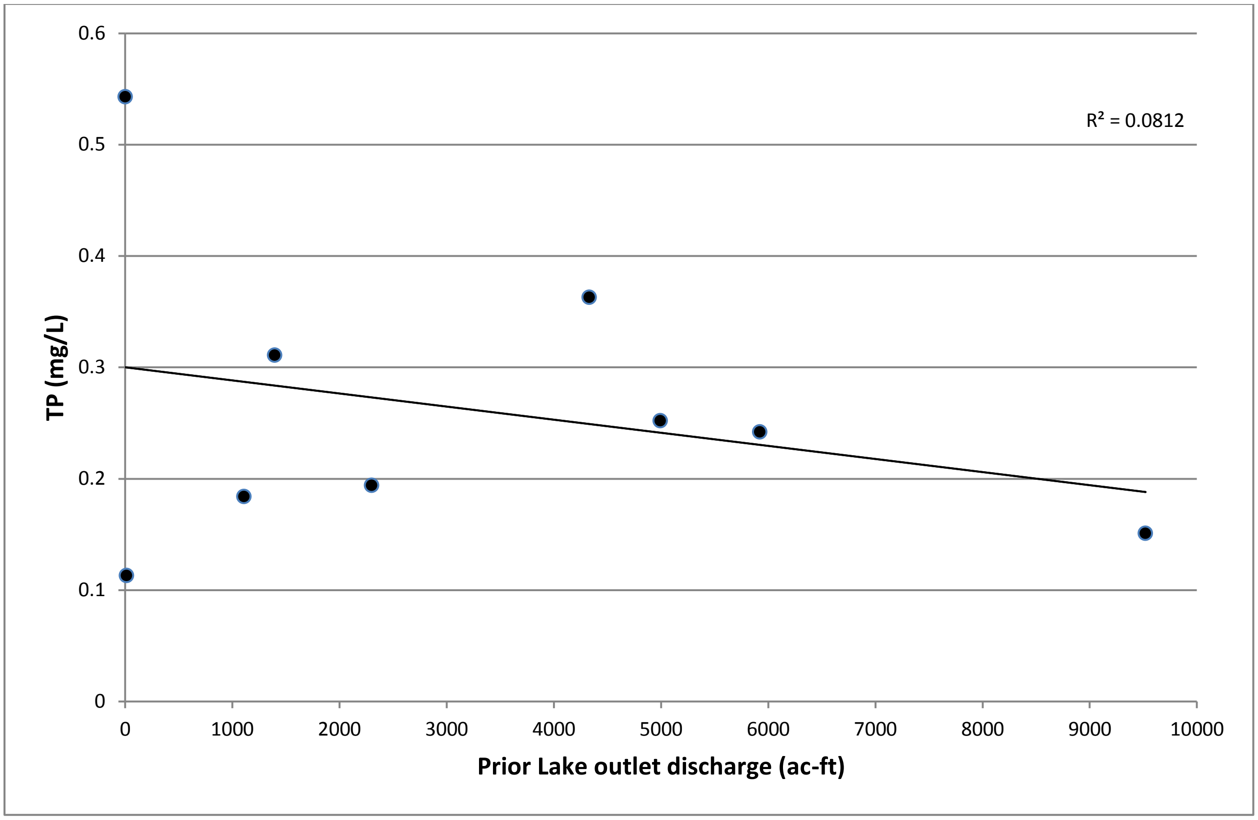


Figure 9. Prior Lake-Spring Lake Watershed District sampling locations along the outlet channel relative to Dean Lake

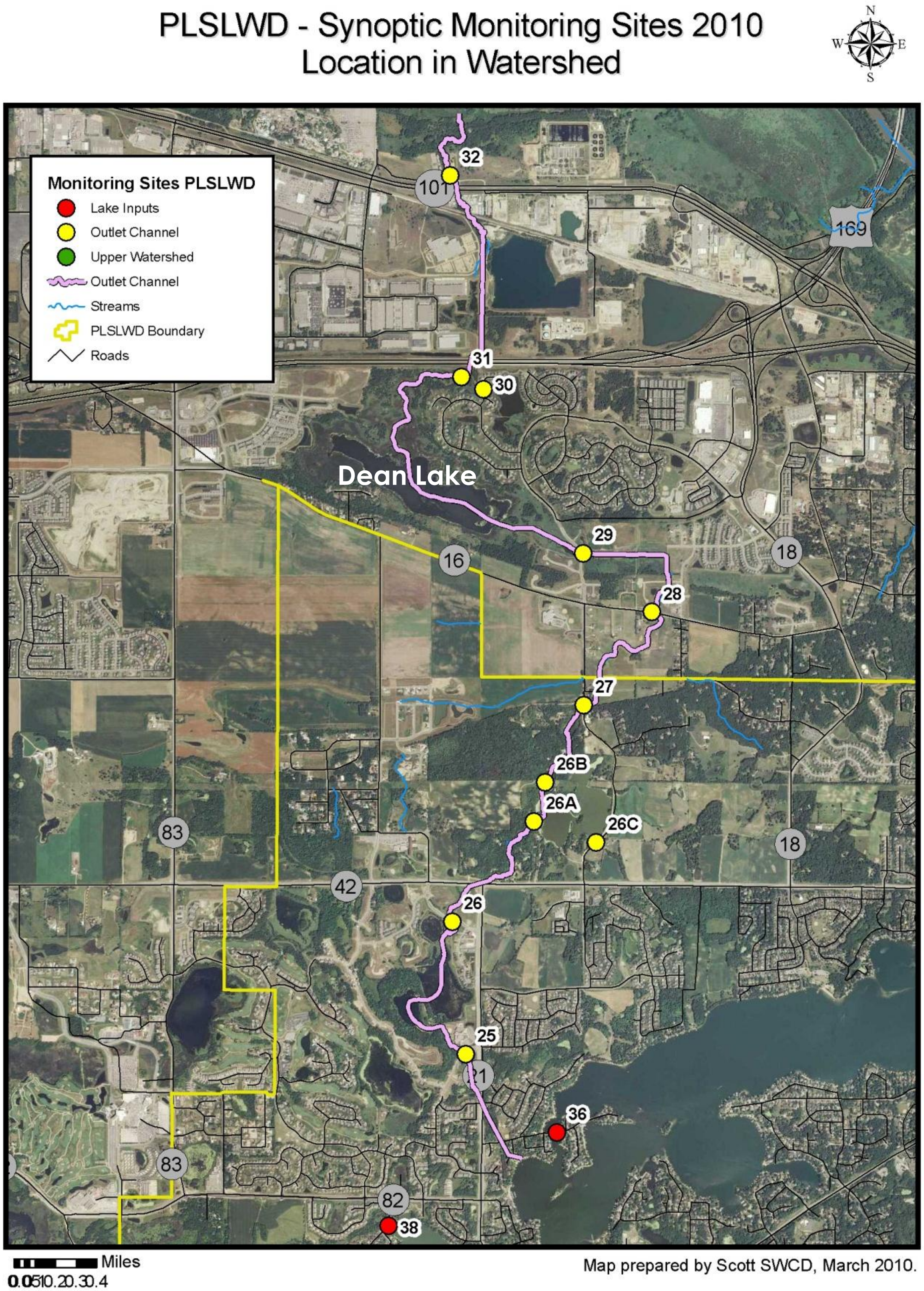


Figure 10. Prior Lake outlet, sampling Site 29, calculated channel flow and total phosphorus data (temporally correlated data shown with link)

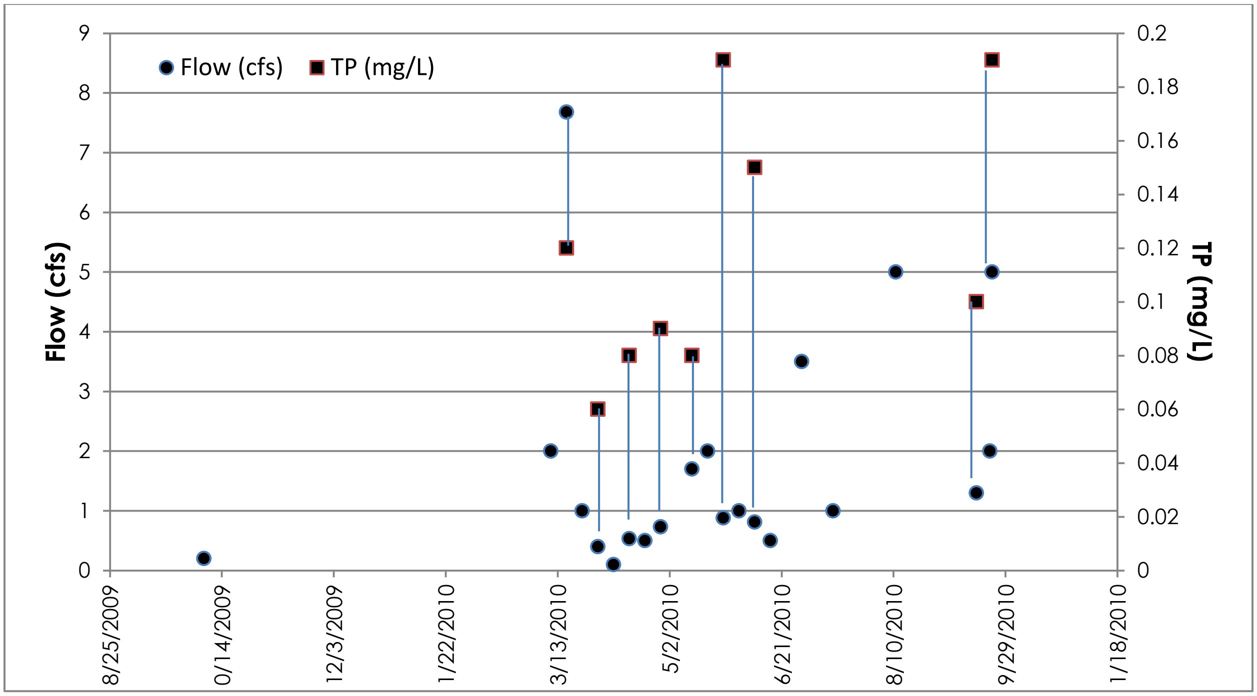


Figure 11. Overlap of data between Dean Lake and the Prior Lake outlet channel, sampling Site 29 (refer to Table 4 for parameters)

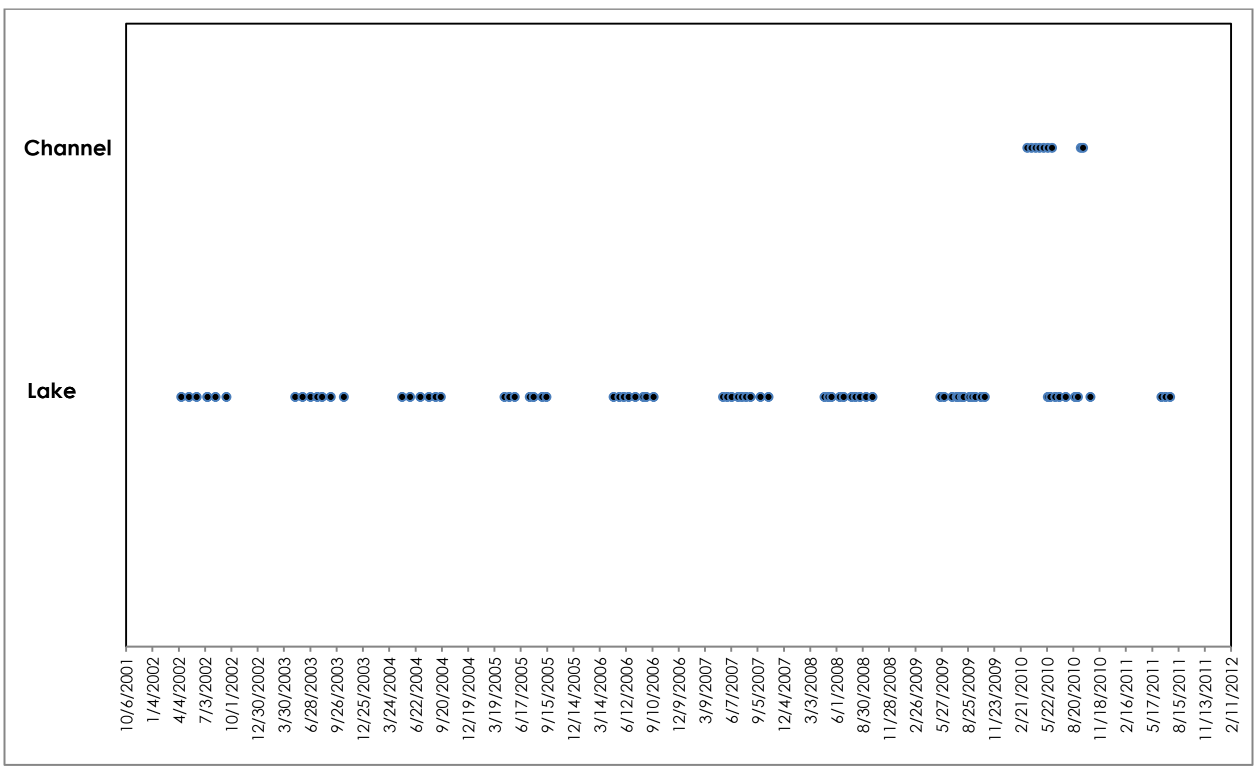


Figure 12. Overlap of data between Dean Lake and the Prior Lake outlet channel, sampling Site 29, for the year 2010 (refer to Table 4 for parameters)

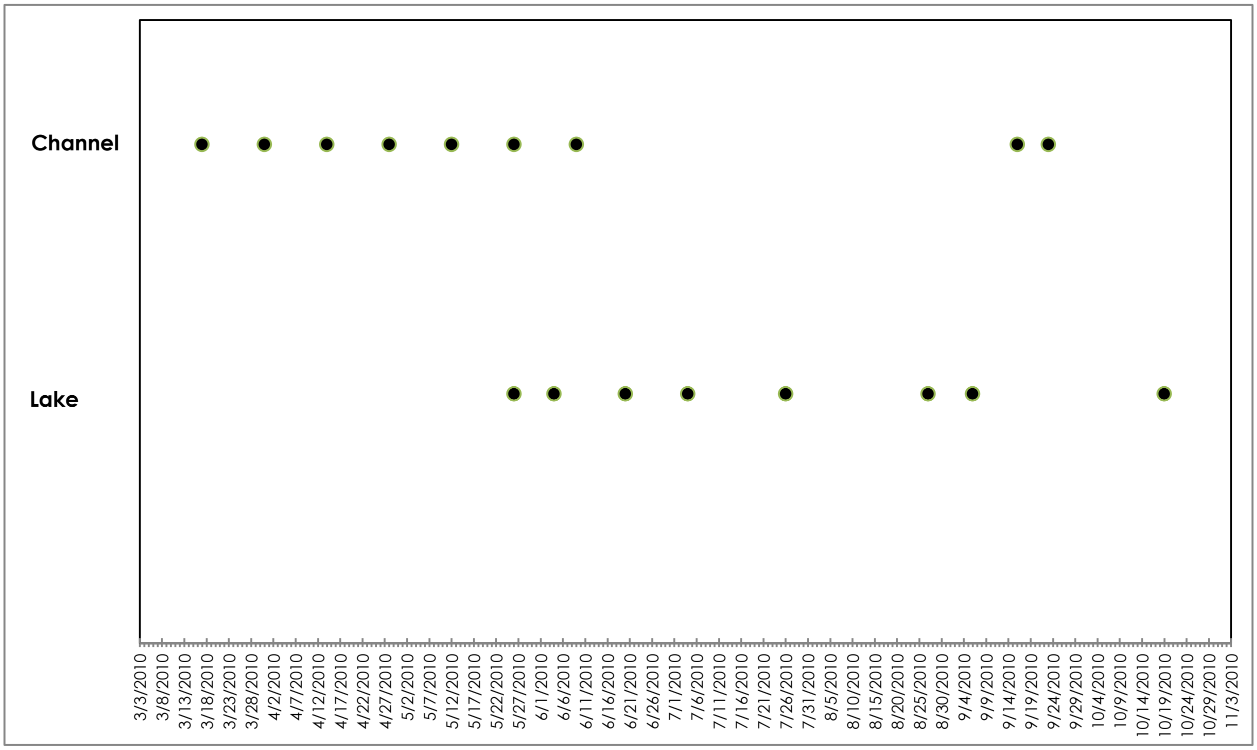


Figure 13. Historic open water/emergent vegetation interface within Dean Lake

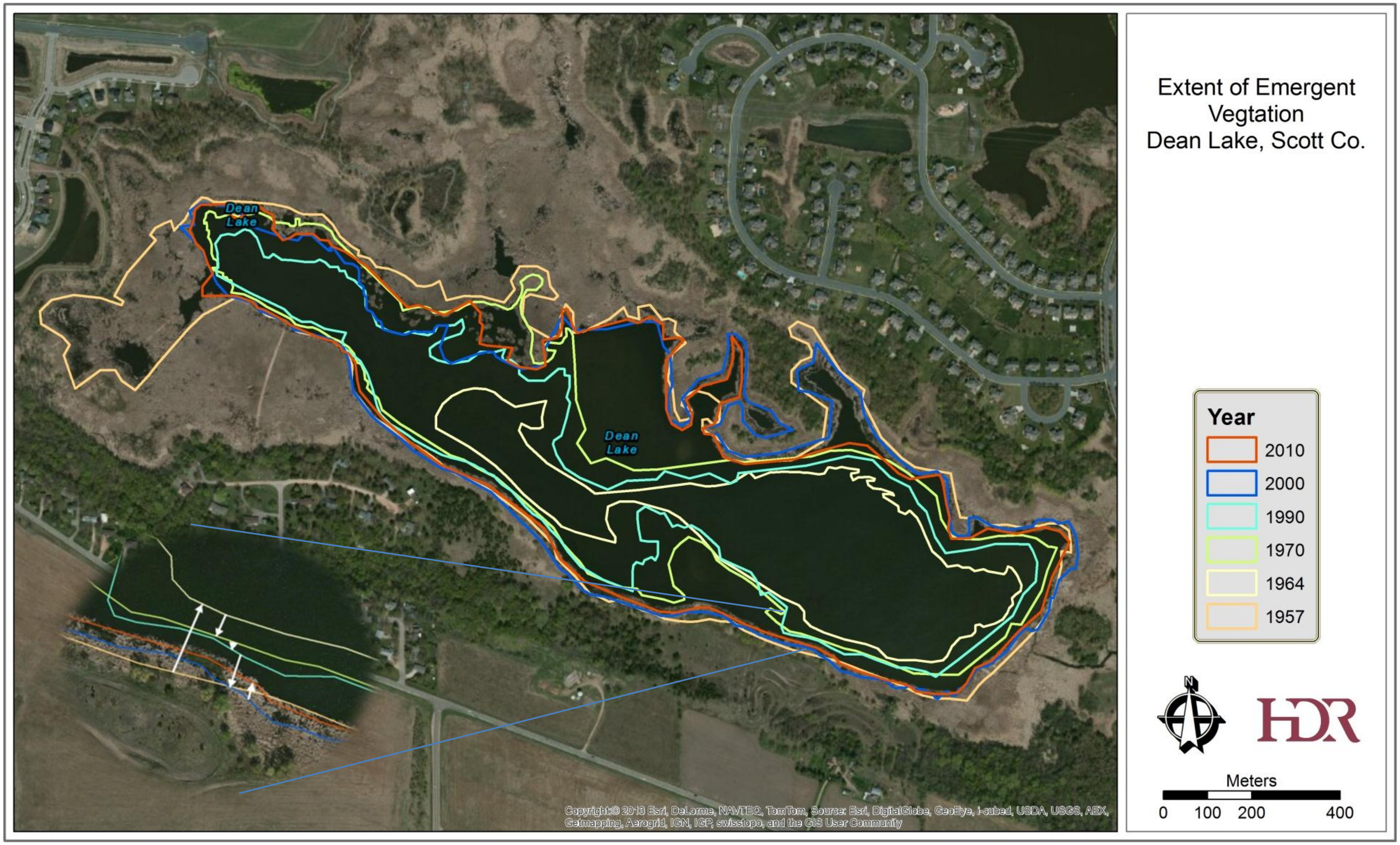


Figure 14. Aggregated and individual native aquatic plant coverage for Dean Lake, September 13, 2013 (green squares = light growth, yellow squares = moderate growth, red squares = heavy growth; McComas and Stuckert, 2013). "Native Plant Coverage" depicts the aggregated assemblage coverage of all sampled native species.

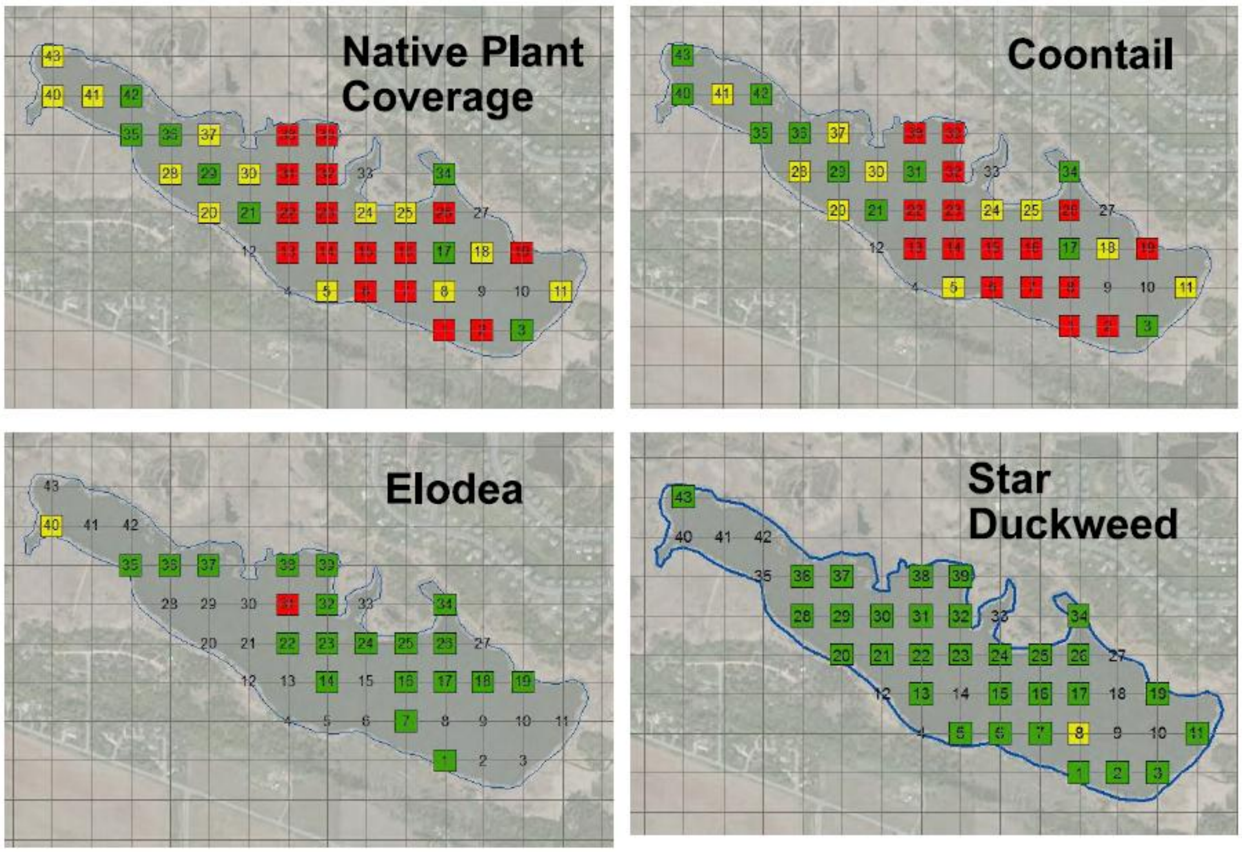


Figure 15. Native emergent and transitional vegetation sampling plots

REFERENCES

City of Shakopee, 1980. *Feasibility Report: Drainage Alternatives, Dean's Lake Outlet Basin IV-A*. Barr Engineering report.

City of Shakopee, 2005. Construction Plan for Dean lake Outlet Structure. WSB plan set for Project Number 1281-88 of City Project 2005-7.

Edwards, A. and K. Twomey, 1982. *Habitat Suitability index Models: Common Carp*. Habitat Evaluation Procedures Group, Western Energy and Land Use Team. U.S. Fish and Wildlife Service.

McComas, S. and J. Stuckert, 2013. *Aquatic Plant Point-Intercept Survey for Dean Lake, Scott County, Minnesota*. Blue Water Science, October 29, 2013

MNDNR, 2005. *Field Guide to the Native Plant Communities of Minnesota: The Eastern Broadleaf Forest Province*. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program. MNDNR St. Paul, MN.

MNDNR-MIS Bureau, 1994. Presettlement Vegetation Geographical Information Systems Shapefile. Minnesota's Bearing Tree Database. Minnesota Department of Natural Resources.

MPCAa, 2013. *Environmental Data Access Website*. http://www.pca.state.mn.us/customPHP/eda/stationInfo.php?ID=70-0074-00-451&ORG=MNPCA. 11/15/2013.

MPCA 2013b. *Minnesota Pollution Control Agency e-Services Website*. http://cf.pca.state.mn.us/water/watershedweb/datasearch/waterUnit.cfm?WID=70-0074-00. 11/15/2013

PLSLWD, 1983. *Memo to District Board of Managers. Prior Lake-Spring Lake Watershed District*. Authored by Bruce Paterson, District Engineer.

PLSLWD, 2013. *2012 Prior Lake Outlet System annual Operations Report*. Prior lake-Spring Lake Watershed District.

Samstad, 1975. *A Report on the Source of Water for Dean lake and Analysis of Potential Development of Dean Lake and Potential Hazards in Other developments Which May Concern the Future of Dean Lake*. A report written for the Lower Minnesota River Watershed District and City of Shakopee.

Scott County, 2008. *Credit River, MN Final Report – Fluvial Geomorphic Assessment, Scott County, MN.*

UMNRSL, 2013. *University of Minnesota's (UMN) remote sensing lab's Lake Browser* http://water.umn.edu/lakebrows.html. 11/15/2013.