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Ground and surface water interaction near a plywood manufacturing facility on the Lake Roosevelt shoreline, Kettle Falls, Washington

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GROUND AND SURFACE WATER INTERACTION NEAR A PLYWOOD MANUFACTURING FACILITY ON THE LAKE ROOSEVELT SHORELINE, KETTLE FALLS, WASHINGTON

BY

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A Thesis
Presented to
the Faculty of
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In Partial Fulfillment
of the Requirements for the Degree
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Paul W. D. Humphreys

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ABSTRACT

From April 1994 to December 1996, a water quality investigation was performed at the Boise Cascade Plywood Plant in Kettle Falls, Washington. This investigation was required by the Washington Department of Ecology to assess possible contamination from the process water lagoon and wet log storage area on the groundwater and nearby Lake Roosevelt. Water samples were collected from 11 groundwater monitoring wells, the lagoon, and two lake-shore seeps, and the samples were analyzed for a variety of chemical parameters. Water elevation data were also collected to evaluate the physical nature of the interaction between ground and surface water.

The primary water bearing zone at the site is the coarse-grained lower aquifer beneath the lagoon area where the occurrence and behavior of groundwater is strongly correlated with Lake Roosevelt. The groundwater elevations in the wells which monitor this aquifer rise and fall with the lake, and very little groundwater gradients were observed between wells. The groundwater beneath the log storage area also rises and falls with Lake Roosevelt, but more substantial groundwater gradients were observed. These gradients appear to be at least partly caused by the finer-grained sediments in this area, where the wells respond more slowly to changes in lake level. The groundwater beneath the log storage area is also generally higher than beneath the lagoon area. This is likely caused by additional groundwater entering the site from the hills to the east. The finer-grained sediments in the log storage area presumably retain this added head longer than the sediments in the lagoon area where the additional head would dissipate relatively quickly in the coarser-grained sediments.

The direction of groundwater flow in the lagoon area is toward Lake Roosevelt when the lake is falling and away from Lake Roosevelt when the lake is rising. In the log storage area, the groundwater gradients indicate groundwater flow toward both the lagoon and the lake. However, a thick section of silt and clay separates the log storage area from the lake, so the majority of groundwater flow out of the log storage area is likely northward via the coarser-grained sediments beneath the lagoon area.

A silt and clay layer overlies the lower coarse-grained aquifer and forms a basin of unconfined perched groundwater beneath the lagoon. This perched groundwater appears to have been impacted by the lagoon with respect to chemical oxygen demand, chloride, total dissolved solids, tannin and lignin and dissolved manganese. The lower aquifer in the lagoon area also appears to have been secondarily impacted to a lesser degree by gradual seepage of these contaminants from the overlying perched groundwater. However, the thick layer of silt and clay at the site largely mitigates surface impacts on the lower aquifer in the lagoon area and on all of the groundwater beneath the log storage area. Activities in the log storage area do not appear to have significantly impacted the groundwater beneath the site.

The perched groundwater beneath the lagoon does not appear to discharge into Lake Roosevelt, and this groundwater is unlikely to directly impact the lake. The groundwater in the lower aquifer beneath the lagoon area is in direct communication with the lake, and over time, any contamination in this groundwater will eventually discharge into the lake.

The seeps do not appear to represent discharge locations for any of the water bearing zones monitored at this site. Rather, the seeps appear to be discharge locations for a second perched groundwater zone which probably exists between the seeps and an unlined stormwater collection area. Infiltrating stormwater would contribute a relatively high organic load to any underlying perched groundwater and would explain the elevated chemical oxygen demand and tannin and lignin concentrations found in the seep water as well as the iron and manganese precipitation observed at the seep outlets.

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INTRODUCTION

Plywood manufacturing generates a considerable quantity of process water which contains a variety of chemicals and suspended solids. To allow reuse of this water for further plywood manufacturing, the suspended solids must first be removed. This is often accomplished by pumping the process water to a man-made pond or lagoon where the suspended solids are allowed to settle from the water before it is pumped back to the processing plant for reuse (Kollock, pers. comm.). Process water ponds and lagoons pose a potential threat to groundwater and hydraulically-connected surface water if they are unlined and the process water is allowed to leach into the subsurface.

Large quantities of logs are required for plywood manufacturing. Prior to processing, the logs must retain a minimum moisture content, and in dry weather, sprinklers are used to apply water in the log storage area (Kollock, pers. comm.). Log storage poses a potential threat to ground and surface water if precipitation or sprinkler water transports the products of wood degradation into the subsurface.

This study examined the potential groundwater contamination from an unlined process water lagoon and wet log storage area at a large lumber processing facility near Kettle Falls, Washington. The subject site is the Boise Cascade Plywood Plant located on the east shore of Lake Roosevelt, approximately 150 kilometers upstream of Grand Coulee Dam (Figure 1). The site is situated at approximately 48° 37' N, 118° 7' W in a relatively flat area between Lake Roosevelt and hills to the east (Figure 2). The facility's process water lagoon dominates the northern portion of the site (Photo 1); the plywood plant, sawmill, shop and office building are situated in the central portion of the site, and the wet log storage and sprinkling area (log deck) is located in the southern portion of the site (Photo 2). See Figure 3.

The extent to which groundwater and nearby Lake Roosevelt have been contaminated from the lagoon and log deck is a function of the hydrostratigraphy of the subsurface, the interaction between ground and surface water, and the contaminant loading rate at the surface. The nature of these systems and their interactions were investigated as they relate to contaminant distributions in the subsurface.

Background

To assess the potential for groundwater contamination beneath the plywood plant, the Washington Department of Ecology (WDOE) issued an Administrative Order to Boise Cascade in May 1991 requesting that a hydrogeologic assessment be performed at the site. In August and September 1992, six piezometers (P-1 through P-6) were installed at the site (CES, 1993). In November 1993, six additional wells were installed (P-1D, P-2D, P-3D, P-4D, P-7 and P-8), and the previously installed piezometers were developed and converted into monitoring wells (Photo 3). The four "D-designated" wells are deep wells which were installed adjacent to four of the previously installed piezometers to allow groundwater monitoring during periods of low groundwater (CES, 1994). Well locations are shown in Figure 3, and the well construction data are summarized in Table 1.

In April 1994, the WDOE requested that Boise Cascade initiate a water quality sampling and analysis program at the site. This program involved collection of groundwater samples from the wells located down-gradient of the log deck and lagoon on a monthly basis, and collection of samples from all of the wells and the lagoon on a quarterly basis. In addition, the three groundwater seeps located on the east shore of Lake Roosevelt were to be sampled once per quarter when accessible and flowing (Photo 4). This sampling program began in April 1994. I began managing this project in January 1995 and continued implementation of the sampling program.

Stormwater Management

To prevent potentially-contaminated surface water from flowing directly into Lake Roosevelt or otherwise leaving the site, all stormwater (from sprinklers, rain or snow-melt) is contained and managed on-site. Ultimately, this water either evaporates or percolates into the subsurface to become groundwater. The stormwater is managed using a variety of sumps, pumps, trenches, slopes and surface impoundments to prevent any stormwater from leaving the site via over-land flow.

In the log deck area, water derived from Lake Roosevelt is pumped to the southeast corner of the deck area and applied to the logs with sprinklers during periods of dry weather. The portion of the sprinkler water, rain or snow-melt which does not evaporate or enter the subsurface flows east across the log deck to a return-flow ditch, and then south to a concrete collection basin. When a storm or snow-melt event occurs which exceeds the capacity of this collection basin, the additional water is pumped to a larger (lined) pond to the south. When conditions in the log yard again become dry, the pond water is pumped back to the collection basin from which it is again applied to the log deck (Figure 3).

The stormwater at other areas of the site is directed (primarily via gravity) to an unlined stormwater collection area west of the sawmill (Figure 3). When the water in this area reaches a certain height, it is pumped to the lagoon where it is mixed with process water from the plywood plant.

Geologic Setting

The site lies within the Columbia River Valley which was primarily formed and shaped by glacial and stream processes. The site itself rests on a series of Quaternary sediments of fluvial, lacustrine and glacial-outburst origin. The fine-grained sediments in the area (silts and clays) represent lacustrine and fluvial overbank deposits. Lacustrine sediments were deposited during the Pleistocene in lakes that periodically formed in the Columbia River Valley behind glacial ice dams in the vicinity of Grand Coulee. The ice dams periodically formed and failed during this period resulting in several episodes of lacustrine deposition followed by fluvial erosion and coarse-clastic deposition. The coarse clastics (sand and gravel) are glacial outwash, fluvial channel lag, and point bar deposits. Approximately 14,000 years ago, glacial activity ceased in the area and the Columbia River proceeded to incise its present channel just west of the site (Breckenridge, 1988 and Kiver, pers. comm.).

The bedrock beneath the site consists of Triassic and Permian marine metasedimentary rocks which are exposed in the east valley sidewall. Immediately west of the site, a north-south trending normal fault is concealed beneath Lake Roosevelt. This shallow east-dipping normal fault separates the bedrock beneath the site from pre-Tertiary orthogneiss and quartzite which are exposed in the west valley sidewall across Lake Roosevelt (Figure 4). The orientation of this fault indicates that the pre-Tertiary rocks to the west are older than the Triassic and Permian rocks to the east. The fault also defines the approximate centerline of the Columbia River Valley in this area (Stoffel, 1991).

Purpose of this Investigation

The unlined process water lagoon and the wet log deck at the site may have released contaminants to the underlying groundwater and thereby degraded the quality of the groundwater and nearby Lake Roosevelt. To determine the extent of the contamination and the nature of the contaminant distributions, it was necessary to:

- Characterize the hydrostratigraphy of the subsurface.
- Determine the dynamics of the ground and surface water interaction.
- Evaluate the extent and nature of the groundwater contamination.

The results of this investigation will allow the operators of this facility to determine if changes to their current water management practices are warranted, will enhance the general understanding of ground and surface water interaction along the Lake Roosevelt shoreline, and should also be relevant to other wood processing facilities with similar operations.

METHODS

Data Collection Procedures

From April 1994 to December 1996, groundwater, lagoon and seep samples were collected at the site. On a quarterly basis, water samples were collected from the lagoon, from the seeps and from all of the groundwater wells. On a monthly basis, groundwater elevations were determined for all of the wells, and groundwater samples were collected from those wells determined to be downgradient of the lagoon and log deck.

Lagoon Sampling and Analysis

The process water lagoon was sampled once per quarter from the east side of the lagoon (Photo 1). The lagoon water was collected at the surface using a mason jar attached to an extension pole, and the sample bottles were filled by simply pouring the contents of the mason jar into the sample bottles. As per the requirements of the WDOE's water discharge permit for the site, the lagoon samples were analyzed for the following chemical parameters: total phenolics, tannin and lignin (T&L), chemical oxygen demand (COD), chloride, total iron and manganese, total dissolved solids (TDS), total suspended solids (TSS), total recoverable petroleum hydrocarbons (TRPH), oil and grease (O&G), formaldehyde and pH (Table 2).

Groundwater Elevation Monitoring

On a monthly basis, the static groundwater elevations were determined for each monitoring well by subtracting the measured depth-to-water from the previously surveyed top-of-casing elevations. The wells determined to be down-gradient of the log deck and process water lagoon were then sampled. Typically, wells P-1, P-1D, P-3, P-3D, P-4 and P-4D were sampled during the monthly sampling events. However, during periods of rapidly increasing groundwater elevations, well P-5 was sometimes found to be downgradient of the log deck and was sampled in lieu of the P-4 wells. All of the wells were sampled during the quarterly sampling events.

Monitoring Well Purging, Sampling and Analysis

Prior to sampling, each monitoring well was purged using a Waterra inertial-lift pumping system with dedicated down-hole tubing (Photo 5). The Waterra pumping system works by rapidly moving the down-hole tubing upward and downward in the water column to alternately set and release a check-ball valve at the bottom of the tubing. In this way the groundwater is moved to the surface in a series of short lifts (Figure 5). The primary advantage of this sampling system over conventional submersible pumps or bailing is the relatively low cost and the low likelihood of cross contamination between wells. As purging progressed, the pH, conductivity, and temperature of the purge water were periodically assessed. Purging continued until these parameters stabilized to within ten percent of two previous readings and a minimum of three well volumes had been removed.

Upon completion of purging, groundwater samples were collected using the inertial-lift pumping system. The samples were analyzed for chloride, COD, TDS, dissolved iron and manganese, total phenolics and tannin and lignin (Table 2). The sample water to be analyzed for dissolved iron and manganese was field-filtered using disposable 0.45-micron water filters. These analyses are a subset of the analyses required for the lagoon and were selected as described below.

COD and TDS were selected for groundwater analysis because relatively high concentrations of these parameters were expected to be present in the process water lagoon -- the presence of comparably high concentrations of these parameters in groundwater would indicate possible lagoon leakage. Chloride was selected for groundwater analysis because it is generally a conservative ion in groundwater systems and can be used to indicate possible connections between different water-bearing zones (Hem, 1992). Relatively high concentrations of dissolved iron and manganese in groundwater would be indicative of reducing conditions in the vadose zone (caused by the presence of downward flowing lagoon or log deck water) which may release dissolved iron and manganese to the groundwater (Hem, 1992). Tannin and lignin are released as wood products degrade under wet conditions, and phenolics are formed as an end-product of lignin degradation (Craven, pers. comm.). These compounds were monitored as indicators of possible impacts to groundwater from both the log-deck sprinkling activities and from the process water lagoon. Phenolics were also specifically tested for because of the known health hazards associated with their consumption (NIOSH, 1994).

Iron and manganese can be present in groundwater as dissolved ions, colloids and suspended solids. Colloids range in size from 0.005 to 0.2 microns, and under certain condition, colloids can be retained in suspension indefinitely. As such, iron and manganese can be transmitted through an aquifer in the both the dissolved and colloidal states (Hem, 1992). The sampling procedure for dissolved iron and manganese analysis involves field-filtering the sample water with 0.45-micron filters. The *dissolved* metals results reported here thus include both the dissolved and colloidal components of the groundwater samples.

Seep Sampling and Analysis

The groundwater seeps located on the east shore of Lake Roosevelt were sampled once per quarter when the lake level was low enough to expose them and they were flowing. Beginning in March 1996, the seep samples were collected from shallow pools created at the outlet of each seep, and a vacuum pump was used to draw the seep water directly into the sample bottles. Prior to this, the seep samples were collected by placing a funnel beneath the seeps and allowing the seep water to flow directly into the sample bottles. The sample collection method was changed to allow sample collection when the lake level was just below the seep discharge location and to limit the amount of sediment collected in the sample bottles.

The seep samples were analyzed for the same parameters as the groundwater samples except that the sample water for the metals analyses was not field-filtered. The seep samples were thus analyzed for total rather than dissolved iron and manganese (Table 2).

Sample Handling and Shipment

All samples were analyzed at Columbia Analytical Services (CAS) in Kelso, Washington which provided constituent-specific sample bottles with sample preservatives, as needed. Field blanks were prepared using de-ionized water supplied by CAS and were analyzed for total phenolics.

All water samples were collected in duplicate to ensure that a complete set of samples was available in the event of sample loss, damage or contamination prior to analysis. The samples were shipped in chilled coolers with custody seals via overnight delivery to CAS. One field blank was placed in each cooler prior to shipment and analyzed for total phenolics. In addition, beginning in July 1996, a trip blank and a laboratory blank were created at CAS using the same deionized water and bottle stock used to create the field blanks. The trip blanks were transported to and from the field with the sample bottles and returned to CAS unopened. The laboratory blanks were stored at CAS. The trip and laboratory blanks were held by CAS for quality control purposes and were only analyzed if phenols were detected in one or more of the field blanks. Strict chain-of-custody procedures were followed, and the chain-of-custody record was signed by the sampler (myself) and by a receiving agent at the laboratory.

Lake Roosevelt Elevation Monitoring

Lake Roosevelt is an approximately 190 kilometer-long reservoir, stretching from Grand Coulee Dam in central Washington to near the Canadian border in northeast Washington (Figure 1). Kettle Falls is approximately 150 kilometers upstream of the dam. The lake elevation is controlled at the dam, and lake elevations vary by as much as 19 meters over the course of a year (Photos 6 - 12). Typically, the lake is lowered from January to May in anticipation of the spring run-off. The lake then rises rapidly from May to July and is relatively stable from July to December (USBR, 1994, 1995 and 1996).

The U.S. Bureau of Reclamation measures the surface elevation of Lake Roosevelt at Grand Coulee Dam every 12 hours and provides these data to the public via a recorded telephone message service. The lake elevations were recorded on a monthly basis, prior to each groundwater sampling event.

The lake elevations reported at the dam differ from the actual lake elevations in Kettle Falls. This is primarily because the lake elevations reported at the dam are measured relative to a different elevation datum than that used to survey the well elevations at the site (Guptill, pers. comm.). Actual elevation variances also exist due to minor flow gradients along the lake (which are a function of inflow rate and lake volume) and differences in atmospheric pressure between Kettle Falls and the dam (Eshbach, 1966). To allow direct comparison of the lake and groundwater elevations at the site, the lake elevation in Kettle Falls was directly surveyed on December 16, 1996 and found to be 0.55 meters lower than the elevation reported at the dam. The lake elevations reported here were thus adjusted downward by 0.55 meters from those reported at the dam. Although this adjustment protocol did not account for temporal changes in the flow gradient and atmospheric pressure variables, these changes were determined to be relatively minor with respect to the total elevation variance between the dam and Kettle Falls.

Statistical Evaluation

Several statistical evaluations were performed on each analytical data set. These were performed to provide for the treatment of analytical data reported to be below the laboratory's reporting limit, to validate the accuracy of the data (outlier evaluation), and to evaluate seasonal or other trends in the data. Each *data set* consisted of the range of analytical results collected at each sampling location (well, seep and lagoon) for each of the analytical parameters listed above. In general, the data were grouped temporally and compared spatially.

The statistical evaluations were performed according to the protocols contained in the WDOE's *Implementation Guidance for the Ground Water Quality Standards* (WDOE, 1996), hereafter "guidance document." The guidance document was written by the WDOE to explain and interpret Chapter 173-200 of the Washington Administrative Code -- *Water Quality Standards for Ground Waters of the State of Washington* (WAC, 1990). The statistical evaluation protocols contained in the guidance document were established to provide consistent statewide procedures for groundwater data evaluation and validation and were partially based on the US EPA's *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Interim Final Guidance* (US EPA, 1989). In addition to the statistical evaluations described in the guidance document, temporal trend analyses were also performed.

Treatment of Analytical Values Below the Laboratory's Reporting Limit

The first statistical evaluation procedure involved estimating constituent concentrations for those data reported to be below the laboratory's method reporting limit (MRL). When a laboratory reports a “none detected” result, the actual concentration of the constituent in question is somewhere between the laboratory’s MRL and zero. To numerically analyze a data set which contains non-detect data, it is necessary to first assign numeric values for the non-detect data based upon the distribution of values in the remainder of the data set. The non-detect results were handled in one of four ways, as prescribed in subsection 13.4 of the guidance document:

> If less than 15 percent of the values in a given data set were below the MRL, the non-detect results were replaced with one-half the MRL. These non-detect (ND) adjusted data were then used to perform all further statistical evaluations.
>
> If 16 to 50 percent of the values in a given data set were below the MRL, Cohen's adjustment was used to estimate the mean and standard deviation of the data set as described in subsection 13.4.1 of the guidance document. To perform the outlier, seasonality and other statistical evaluations, the non-detect results were replaced with one-half of the MRL.
>
> If 51 to 90 percent of the values in a given data set were below the MRL, Aitchison's adjustment was used to estimate the mean and standard deviation of the data set as described in subsection 13.4.2 of the guidance document. To perform the outlier, seasonality and other statistical evaluations, the non-detect results were replaced with zero.
>
> If greater than 90 percent of the values in a given data set were below the MRL, the non-detect results were replaced with zero and the average concentration of the contaminant of concern was assumed to be below the MRL.

Outlier Evaluation

Outliers are data points which do not appear to fit with the data set from which they were derived. An outlier can result from sample handling, laboratory, transcription or other errors, or may represent an actual extreme in the water quality condition. The outlier evaluations were performed as described in subsection 13.2 of the guidance document. When an outlier was identified, the raw and ND-adjusted data were checked for possible transcription, laboratory or other errors, and corrections were made as appropriate. If an error was found, but the correct value could not be determined, the incorrect value was deleted from the database. If a value was determined to be an outlier, but no error could be identified, no adjustment was made. Once an outlier adjustment was made to given data set, the outlier-evaluation procedure was performed again until no further outliers were identified.

Seasonal and Lake-level Correlation Analysis and Seasonality Adjustments

Prior to performing the seasonality adjustments recommended in the guidance document, each data set was evaluated to determine if the observed data variation was correlated with the month of sampling and/or with changes in lake elevation. These evaluations were performed using the statistical analysis software *Statistix for Windows,* which calculated correlation coefficients and P-values for each data set versus the month of sampling and lake elevation. A statistically-significant correlation is generally indicated by a P-value of less than 0.05 and a correlation coefficient of greater than 0.1, with a negative (or inverse) correlation indicated by a correlation coefficient of less than -0.1 (Statistix, 1996).

The EPA recommends that "corrections for seasonality should be used with great caution..., and there should be a good scientific explanation for the seasonality as well as good empirical evidence for the seasonality before corrections are made" (EPA, 1989). No statistically-significant correlations were observed in the majority of the data sets with respect to the month of sampling or lake elevation. It would thus have not been appropriate to seasonally-adjust those data sets where no seasonal correlation could be identified. In those data sets where seasonal correlations were identified, the seasonality adjustments would have masked some important trends in the analytical data, as well as downward-adjusted several of the data points to negative values. As a result, no seasonality adjustments were performed. The data sets in which significant seasonal correlations were identified are discussed in the Analytical Variation and Lake Level subsection below.

Temporal Trend Analysis

To account for changes in water quality over time which may have been independent of cyclical seasonal variation, temporal trend analyses were performed. These were done by performing unweighted least-squares linear regressions on each data set using the Statistix analytical software. A statistically-significant upward or downward temporal trend is indicated by a P-value of less than 0.05 (Statistix, 1996). In those data sets where significant temporal trends were indicated, the R-squared values and regression coefficients were also reported. R-squared is the square of the correlation coefficient which measures the overall deviation from the "best fit" line of the regression. R-squared values range from 0 to 1, with 1 being an exact fit. The regression coefficient is the coefficient of the linear regression which measures the "strength" of the temporal trend, i.e., the slope of the "best fit" line -- negative values indicate a decreasing trend through time; positive values indicate an increasing trend through time.

Analytical Data Evaluation

Once the data were validated and adjusted according to the guidance document protocols, all of the data were summarized in tables, and means, standard deviations, and 95% confidence intervals were calculated for each data set. The mean and confidence interval data were then presented in column charts for each analytical parameter. Charts were also prepared for those data sets where statistically-significant temporal trends were identified, and chemical-distribution contour maps were prepared to illustrate the spacial distribution of the analytical data through time.

The above procedures were used to establish the distribution of contaminants throughout the groundwater system. The lagoon analytical data were then compared with the groundwater data to determine if significant groundwater contamination from the lagoon was indicated. Finally, the groundwater data were compared with the seep analytical data to identify the probable groundwater source for the seeps.

Hydrogeologic Assessment

To understand the contaminant distributions in the groundwater and to assess the potential for contaminant migration to Lake Roosevelt, it was necessary to characterize the hydrostratigraphy of the study area. The hydrostratigraphy beneath the site was evaluated using the available boring logs (which were converted to metric units and condensed to a single page), and four geologic cross-sections of the site were prepared.

Groundwater contour maps were prepared for each month of groundwater elevation data to characterize the flow of groundwater across the site at various times of the year and during various lake level stages. Hydrographs of the groundwater and lake elevation data were then prepared to characterize the physical nature of the interaction between the lake and groundwater.

The groundwater elevation and chemical distribution contour maps were prepared using the *Surfer for Windows* computer contouring software. The contouring method used was *Kriging,* the default contouring method of the software. According to the software authors, Kriging is appropriate for use with irregularly spaced data and "generates the best overall interpretation of most data sets." The elevation and chemical concentration data from wells P-1D, P-2D, P-3D, P-4D, P-5, P-7 and P-8 were used to prepare the contour maps. These wells were selected because uninterrupted data streams were generally available for all of these wells, all monitored the primary water-bearing zone at the site, and all were screened over approximately the same elevation range (+/- 4 meters). The chemical distribution contour maps were prepared for COD, chloride, TDS and dissolved iron in groundwater. Preparation of contour maps for the other contaminants of concern (T&L, total phenolics and dissolved manganese) was not done because most of the wells did not have measurable concentrations of these contaminants.

RESULTS & DISCUSSION

Site Stratigraphy

Stratigraphic summaries and well construction diagrams for each of the monitoring wells are shown in Appendix A, and these were used to prepare four stratigraphic cross sections of the site (Figures 6, 7, 8 and 9). As shown in these cross sections, the site rests on a series of fluvial and lacustrine sedimentary layers. The bedrock beneath the site consists of Triassic and Permian metasedimentary rocks of marine origin which are exposed in the east valley sidewall (Figure 4).

Four main periods of deposition are indicated at the site: two episodes of fluvial deposition interlayered with two episodes of lacustrine deposition. The uppermost depositional unit consists of sand, sandy gravels and gravels. The deepest portion of this unit lies beneath the lagoon area where it extends from the surface to approximately 13 meters below ground surface. To the south beneath the northern end of the log deck, this unit shallows to approximately 4 meters, and then deepens to approximately 8 meters beneath the southern end of the log deck (Figure 6).

The second depositional unit consists of glaciolacustrine silts and clays. These fine-grained sediments are approximately 11 meters thick beneath the northern lagoon area, approximately 3 meters thick beneath the southern lagoon area, and 10 to 17 meters thick beneath the log deck. The silts and clays shallow and thicken to the north and south of the southern lagoon area and form a basin for the perched groundwater monitored at well P-3 (see discussion below). These sediments also form a partial confining layer throughout the site between the two hydraulically-conductive units above and below.

The third depositional unit consists of gravel and sand. This unit is approximately 5 meters thick beneath the northern lagoon area and approximately 14 meters thick beneath the southern lagoon area. Beneath the log deck, these sediments are approximately 12 meters thick on the north and approximately 1 meter thick on the south. From east to west across the log deck, the gravels and sands feather into the upper silt and clay layer which joins another silt and clay layer below (Figure 9). Across the lagoon area from east to west, the sand and gravel layer is continuous to the lake, and the lower silt layer exists as a thin lens approximately 1 meter thick (Figure 7). This lens of silt may or may not be continuous with the thick silt layer to the south.

Underlying the lower gravel and sand unit to the north and the silt and clay unit to the south is the metamorphic bedrock described above. These rocks were described on the original boring logs as phyllite and appear to be an erosional surface dipping west toward Lake Roosevelt (Figure 9). This bedrock defines the eastern hydraulic boundary for the groundwater and at least a portion of its base. The permeability of the bedrock is presumably low, and significant quantities of groundwater are probably not transmitted between the bedrock and the sediments.

Groundwater and Lake Elevations

The groundwater elevations for all of the wells and the surface elevation of Lake Roosevelt are summarized in Table 3, and hydrographs of the lake and groundwater elevations are shown in Figures 10 and 11. As shown in these figures, the groundwater elevations in ten of the twelve wells follow the elevation changes in Lake Roosevelt. The two wells which do not follow the changes in lake elevation, P-3 and P-6, monitor groundwater zones which are largely independent of the lake.

Well P-3 was installed approximately 30 meters west of the south end of the lagoon (Figure 3), in the unconfined coarse sediments which overlie the first silt and clay layer. As discussed above, the silt and clay in this area form a basin in which perched groundwater collects as it migrates downward from the surface (Figures 6 and 8). Although the P-3 groundwater elevations do not follow the changes in lake elevation, it appears that the perched groundwater in this area is recharged slightly when the lake occasionally rises above the elevation of the perched groundwater (Figures 8 and 10). Alternatively, the small groundwater elevation rises observed in P-3 could be related to seasonal increases in precipitation infiltration.

Well P-6 was installed approximately 40 meters west of the log deck on the western property boundary (Figure 3), and the screen for this well was positioned in a three-meter thick section of sandy silt among the surrounding silt and clay (Figure 9). This silty sand is in relatively close proximity to the silty sand in the area of well P-5's screened interval.

However, as shown in Figure 11, the P-5 groundwater elevations follow the changes in lake elevation while the P-6 groundwater elevations generally do not. This indicates that groundwater is generally not transmitted between these areas of silty sand due to the low hydraulic conductivity of the intervening silt and clay.

The groundwater monitored at P-6 was approximately two meters higher than the highest lake level for most of this study, but P-6 did respond to the large lake elevation changes beginning in May 1996 (Figure 11). This indicates that the silts and clays between P-6 and the lake are normally saturated and that the groundwater monitored at P-6 is not completely independent of the lake. When the lake level is lowered, groundwater gradually discharges from the near-shore silts and clays, and a steep discharge profile slowly moves landward toward the log deck. The large lake draw-down in 1995 was of insufficient magnitude or duration to allow the discharge profile to intercept the silty-sand monitored at P-6. However, in the larger 1996 draw-down, P-6 was intercepted by the discharge profile causing the groundwater levels to decline in this area. When high lake levels returned in July 1996, the groundwater slowly rose in P-6, and by December 1996 the groundwater elevation in P-6 was again the highest monitored at the site. This groundwater had not, however, risen to its former elevation. Barring another lake draw-down of the magnitude seen in 1996, P-6 will probably slowly return to its former elevation, recharged by an as yet unidentified groundwater source in addition to the lake.

The groundwater elevations in the lagoon area wells (P-1, P-1D, P-2, P-2D, P-3D and P-8) and the northern-most log deck area wells (P-4 and P-4D) follow the elevation changes in Lake Roosevelt very closely (Figure 10). These wells have a strong hydraulic connection with the lake due to the coarse-grained sediments in this area's saturated zone. Strong hydraulic connections also appear to exist between the wells which monitor this area, as very little groundwater gradients were observed between wells. The maximum variance from the mean groundwater elevation was less than 0.01 meters in 9 of the 33 months of elevation monitoring, less than 0.02 meters in 17 of 33 months, less than 0.10 meters in 32 of 33 months, and always less than 0.17 meters (Table 3). In general, the groundwater elevation variance was greater when the lake level was rising or falling rapidly. Some of the groundwater elevation variance can also be attributed to the inherent error in the elevation measurement technique. This error is a function of the accuracy of the top-of-casing surveying (approximately +/- 0.005 meters), random error in the depth-to-water measurements (approximately +/- 0.005 meters), and possible recording or transcription errors. These data were carefully scrutinized and reviewed, however, and there are likely very few (if any) recording and transcription errors. The relative distances between the wells and the lake did not appear to have a significant effect, at least with respect to the one-month measurement period used in this study.

The groundwater elevations in the log deck area wells (P-5 and P-7) also rise and fall with the lake, but they are not correlated as strongly with the changes in lake elevation as are the lagoon area and P-4 wells (Figure 11). The P-5 and P-7 groundwater elevations in the log deck area were generally higher than the lagoon area and lake elevations. The P-7 groundwater elevations were always higher than the lagoon area groundwater elevations and were also always above the lake, except on two occasions, when the lake had risen rapidly following a large draw-down (Figure 11). The P-5 groundwater elevations were generally higher than the lake, but this well responded very slowly to changes in lake level, and always lagged behind the changes in P-7. During periods of rapid lake level rise, the P-5 elevations sometimes lagged behind the lagoon area wells, and on five occasions the P-5 elevations were lower than the P-4 and P-4D elevations. On these occasions, P-5 was considered to be the downgradient well in the log deck area and was sampled in lieu of the P-4 wells. P-5 is screened in finer-grained sediments than most of the other wells at the site (Figure 9), and as a result, the groundwater in this well responds more slowly to changes in lake elevation.

The reason for the generally higher groundwater elevations in the log deck area is probably related to an additional input of water from the hills east of the site. Such groundwater likely enters the site via the lower sand and gravel aquifer which rests on the bedrock to the east of the site (Figures 6 and 9). I suspect that the land-derived portion of the groundwater is relatively small compared to that coming from the lake, but in the finer-grained sediments of the log deck area, it is significant enough to noticeably raise the groundwater levels. From the lagoon area south to the P-4 wells, the sediments are much coarser, and any added head from the east would dissipate more quickly. There is also more topographic relief east of the log deck than to the east of the lagoon area (Figure 2), so more land-derived groundwater may simply flow into the log deck area of the site. The log-sprinkling activity in the log deck might provide additional groundwater to the log deck area; however, the overlying silt and clay layer likely prevents this from being a significant source.

The hydraulic conductivity of the silt and clay sediments appears to vary across the site. These sediments appear to have a lower hydraulic conductivity in the vicinity of the lagoon, where the perched groundwater monitored at well P-3 is located, and a somewhat higher overall conductivity in the log deck area where these sediments are presumably saturated and slowly transmit some groundwater to and from the lake.

The groundwater elevation contour maps prepared for each month of groundwater elevation data are shown in Appendix B, and four of these are also shown as Figures 12, 13, 14 and 15. Figure 12 is representative of relatively stable lake and groundwater conditions. From the lagoon area south to the P-4 wells, there was virtually no groundwater gradient, and all of the groundwater elevations were within 0.08 meters of the lake elevation. In the log deck area, P-5 had the highest elevation, and the groundwater gradients were generally to the north (toward the lagoon area) and west (toward the lake). Figure 13 is representative of a rapidly falling lake and groundwater conditions, and a lakeward flow of groundwater is seen from the lagoon area. In the log deck area, increased groundwater gradients are seen, indicating increased groundwater flow toward the lagoon and the lake. However, given the fine-grained sediments between the log deck and the lake, the majority of groundwater flow out of the log deck area likely occurs indirectly via the coarser sediments in the lagoon area to the north (Figure 9). Figure 14 is representative of rising lake and groundwater conditions and shows inland groundwater gradients across the site. Well P-5 responded more slowly to the changes in lake elevation than P-7, and as a result, P-5 became downgradient of P-7. Figure 15 shows the groundwater elevations one month after those shown in Figure 14 and represents a continuing rise in the lake and groundwater elevations. In this instance, P-5 became the most down-gradient well at the site, presumably due to the relatively low hydraulic conductivity of the silty sediments in this well's vicinity. In these figures, the closure of the contour lines on the east side of the log deck is an artifact of the contouring method caused by the lack of elevation data to the east. The actual groundwater gradients east of the log deck presumably grade upward with the topography.

In summary, the groundwater wells at this site cannot be assigned the traditional labels of *upgradient* and *downgradient* for the purpose of designating *background* and *compliance* groundwater monitoring locations. Lake Roosevelt is alternately both the source and receptor for the groundwater beneath the site depending on whether the lake is rising or falling. The periodic gradient reversals observed between P-5 and P-7 appear to be a function of differing response rates to changes in lake level and may not represent significant changes in the direction of groundwater flow. The direction of groundwater flow in the lagoon area is toward Lake Roosevelt when the lake is falling and away from Lake Roosevelt when the lake is rising. In the log deck area, the groundwater also rises and falls with Lake Roosevelt, but additional land-derived groundwater from the east appears to increase the groundwater elevations in this area. The primary direction of groundwater flow from the log deck area appears to be to the north, with greater flow when the lake level is dropping and thus reducing the hydraulic head in the lagoon area.

Seep Hydraulics

To allow correlation of the seep analytical data with the groundwater analytical data, the seep discharge elevations were measured by a licensed surveyor on December 16, 1996. The seep elevations were measured at sample collection pools located just below the seep discharge locations. The Seep A and B elevations were both 390.8 meters, and the Seep C elevation was 391.4 meters (1929 Coastal and Geodetic sea level datum). The Seep C elevation was not measured at a sample collection pool since an insufficient amount of water flows from this seep to form a pool. The location selected by the surveyor for the Seep C elevation measurement may thus have not been in the same relative position as was selected for Seeps A and B.

The seep discharge elevations reported above did not appear to fluctuate substantially over the course of this investigation. Since these seeps continue to discharge when the groundwater in the lower aquifer is well below the seeps, the seeps do not appear to be discharge locations for this aquifer. Instead, the seeps appear to be discharge locations for perched groundwater lying above the upper silt and clay layer at the site (Figure 8).

The groundwater zone monitored at P-6 is approximately 420 meters away from the seeps and is separated by P-5 where no perched groundwater was encountered (Figure 3). In addition, the water-bearing zone from which P-6 derives its water is considerably lower than the seep elevations and is separated from the seep discharge area by a thick section of silt and clay (Figure 9). It is thus unlikely that the groundwater monitored at P-6 discharges at the seeps. The seeps could be discharge locations for the perched groundwater monitored at P-3 (which is approximately 350 meters feet from the seeps), or they could be discharge locations for another perched groundwater zone which lies closer to the lake shore. In addition to the lake, the most-likely recharge area for such a perched groundwater zone would be the unlined stormwater collection area approximately 150 meters northeast of the seeps (Figures 3 and 8). See below for further discussion.

Analytical Data Summary and Comparison

Overall, 103 analytical data sets were evaluated according to the statistical methodology described above, and all of the ND-adjusted groundwater, seep and lagoon analytical data are summarized in Tables 4, 5 and 6. The ND-adjusted means of each data set all are summarized in Table 7, and the mean values for each of the groundwater analytical parameters are compared graphically in Figures 16 to 22. As shown in these figures, and as discussed below, considerable analytical variability was found among the various groundwater wells at the site. Some of this variability may be related to localized impacts to groundwater, or alternatively, some of the wells at the site may simply exist in areas with naturally higher constituent concentrations.

It was not possible to evaluate these data with respect to established background water quality data. As discussed above, the lake is both the primary source and ultimate receptor for groundwater beneath the site, and some additional groundwater likely enters the site from the hills to the east. Nonetheless, by comparing the groundwater conditions at the various monitoring locations, and by comparing the groundwater data to the lagoon and seep data, it was possible to make some reasonable determinations concerning how activities at the site may have impacted the groundwater quality.

Chemical Oxygen Demand (COD)

In the lagoon area wells, the mean COD concentrations ranged from 3 to 54 mg/L with an average mean of 20 mg/L. The lagoon had a mean concentration at 1,800 mg/L, and Seeps A and B had mean concentrations of 43 and 54 mg/L, respectively. In the log deck area wells, the mean COD concentrations ranged from 2 to 13 mg/L with an average mean of 7.2 mg/L (Figure 16). Although there is a substantial difference in the COD concentrations between the lagoon and the perched groundwater at P-3 (where the highest groundwater COD concentration was observed), it appears that the lagoon may be responsible for the somewhat elevated COD concentrations in P-3. However, as shown in Figures 27 and 34A, the COD concentrations in both P-3 and the lagoon decreased significantly over the course of this investigation. The COD concentrations at the seeps were similar to those measured in P-3, indicating a possible linkage with P-3 or some other groundwater zone with an elevated organic load.

The chemical distribution contour maps for COD reveal a fair amount of variation in the COD distribution through time (Appendix C, page 161). The highest COD concentrations were generally centered in the vicinity of well P-1D to the east of the lagoon. The changes in COD concentrations at P-1D were strongly correlated with changes in lake elevation (Figure 23A), while the changes at P-3D were negatively-correlated with changes in lake elevation (Figure 25A). These changes may be caused by the flushing of organic-laden groundwater back and forth between P-1D and P-3D as the lake and groundwater elevations rise and fall. In the log deck area, well P-5 had the highest COD concentrations during the first three quarters of this investigation, but from March 1995 onward, the P-5 concentrations decreased, leaving well P-7 with the highest COD concentrations in this area.

Chloride

In the lagoon area wells, the mean chloride concentrations ranged from 33 to 330 mg/L with an average mean of 130 mg/L (P-3 had the highest concentration). The lagoon had a mean concentration of 310 mg/L, and Seeps A and B had mean concentrations of 12 and 11 mg/L, respectively. In the log deck area wells, the mean chloride concentrations ranged from 1 to 19 mg/L with an average mean of 10 mg/L. The P-4 wells had the highest mean chloride concentrations in the log deck area (Figure 17).

Chloride is generally considered to be a conservative ion in groundwater systems and can often be used as a tracer to establish possible hydraulic links between different water bearing zones. The P-3 and lagoon mean chloride concentrations differed by only seven percent, indicating a linkage between the lagoon and perched groundwater monitored at P-3. All of the lagoon area wells had substantially higher chloride concentrations than the log deck area wells, indicating a fairly low degree of mixing between these zones. A moderate degree of mixing may be indicated at the northern end of the log deck, however, where the P-4 wells are located. There is also some indication that the elevated chloride concentrations in the perched groundwater may have contributed to the relatively higher levels of chloride in the lower aquifer beneath the lagoon area.

The mean chloride concentrations at the seeps are considerably lower than the P-3 chloride concentrations. This suggests that the seeps are probably not discharge locations for the perched groundwater monitored at P-3. Rather, the seeps appear to be discharge locations for a separate perched groundwater zone which lies closer to the lake shore (Figure 8).

The chemical distribution contour maps for chloride in groundwater show the highest concentrations in the lagoon area, with P-3D usually having the highest concentrations among the deep wells at the site (Appendix C, page 173). On two occasions, well P-1D had the highest chloride concentrations at the site, and the changes in P-1D were correlated with changes in lake elevation (Figure 23B). The chloride concentrations in P-2D and P-3D were negatively-correlated with changes in lake elevation (Figures 24 and 25B). These correlations and the general changes in the lagoon-area chloride distributions indicate that the chloride plume is flushed back and forth beneath the lagoon area as the lake and groundwater elevations rise and fall.

Total Phenolics

Phenolics have generally not been detected above the laboratory's detection limit of 0.01 mg/L in the groundwater or seeps at the site (Figure 18). When phenolics were detected, they were also usually found in the field blanks, often in concentrations above those found in the samples (Tables 4C-1 and 4C-2). I suspect that laboratory contamination accounts for the occasional phenolics detections in some of the seep and groundwater samples. As described above, I instructed the laboratory to initiate additional quality control procedures in July 1996 in an attempt to alleviate this problem. Since that time, no further phenolics have been detected in any of the groundwater samples. Due to the overall lack of non-zero phenolics data for groundwater, no chemical distribution contour maps were prepared for this parameter.

In the lagoon, the mean total phenolics concentration was 0.33 mg/L, and concentrations have generally decreased through time (Figure 34C). With respect to total phenolics, there is no evidence of any impacts to the groundwater monitored beneath the site. A somewhat elevated mean phenolics concentration of 0.01 mg/L was found at Seep B. However, given the problems with the phenolics analyses, this result is suspect. In addition, this value was based on an average of six samples where a single detection of 0.06 mg/L was averaged with ND results in the other five samples.

Total Dissolved Solids (TDS)

In the lagoon area wells, the mean TDS concentrations ranged from 430 to 1,500 mg/L with an average mean of 800 mg/L. The lagoon had a mean concentration of 2,100 mg/L, and Seeps A and B had mean concentrations of 620 and 670 mg/L, respectively. In the log deck area wells, the mean TDS concentrations ranged from 270 to 480 mg/L with an average mean of 390 mg/L. The P-4 wells had the highest mean TDS concentrations in the log deck area (Figure 19).

These results also suggest a possible impact from the lagoon on the perched groundwater monitored at P-3. P-3 had the highest mean TDS concentration for groundwater, which was approximately 70% of the mean TDS concentration in the lagoon. However, as shown in Figures 29A and 34A, the TDS concentrations in both P-3 and the lagoon have decreased significantly over the course of this investigation. Some gradual transmission of TDS from the perched groundwater to the lower aquifer may be indicated due to the relatively higher TDS concentrations observed throughout the lagoon area. In addition, the TDS concentrations in the P-4 wells, which were greater than in the other log deck wells but below most of the lagoon area wells, again indicates that some groundwater mixing is occurring between the lagoon area and log deck area on the north end of the log deck.

The chemical distribution contour maps for TDS in groundwater are shown in Appendix C, beginning on page 185. The highest TDS concentrations in the deep wells were generally centered around well P-3D, although higher TDS concentrations were sometimes observed in wells P-1D and P-2D. The TDS concentration changes in P-1D were strongly correlated with changes in lake elevation (Figure 23B), and the changes in P-3D were negatively-correlated (Figure 25C). The changes in the TDS distributions are similar to those observed in the chloride distributions, and the TDS plume also appears to be flushed back and forth beneath the lagoon area as the groundwater and lake elevations rise and fall.

Tannin and Lignin (T&L)

In the lagoon area wells, the mean T&L concentrations ranged from less than 0.2 to 0.9 mg/L with an average mean of 0.29 mg/L. In the log deck area wells, the mean concentrations ranged from 0.05 to 0.2 mg/L with an average mean of 0.09 mg/L. The lagoon had a mean T&L concentration of 46 mg/L, and Seeps A and B had mean concentrations of 3.2 and 2.7 mg/L, respectively (Figure 20).

Activities in the log deck area do not appear to have impacted groundwater with respect to T&L, but the lagoon may have had a moderate impact on the groundwater monitored at P-3 and P-1D. The elevated T&L concentrations found at the seeps again suggests that the suspected perched groundwater zone near the seeps has been impacted from the nearby stormwater collection area. Comparison of the seep T&L concentrations to P-3 (which had a mean concentration of 0.60 mg/L) indicates that the P-3 groundwater does not discharge at the seeps.

Given the overall lack of non-zero T&L data for the deep groundwater wells, no chemical distribution contour maps were prepared for this parameter.

Iron and Manganese

The mean dissolved iron concentrations in the lagoon area wells ranged from 30 to 51 ug/L with an average mean of 41 ug/L. In the log deck area wells, the mean dissolved iron concentrations ranged from 34 to 89 ug/L with an average mean of 61 ug/L (Figure 21). All of the wells had dissolved iron concentrations well below the Washington maximum contaminant level (MCL) for drinking water of 300 ug/L. No problem appears to exist with respect to dissolved iron in the groundwater monitored at this site.

The average dissolved manganese mean in the lagoon area wells was 320 ug/L, but the mean values varied widely in this area. P-3D and P-8 had mean concentrations of less than 5 ug/L, while P-1D and P-3 had mean concentrations of 2,020 and 160 ug/L, respectively. The remaining wells in this area (P-1, P-2 and P-2D) had mean concentrations of 22, 42 and 0.6 ug/L, respectively. In the log deck area wells, the mean concentrations ranged from less than 5 ug/L to 28 ug/L. The average mean in the log deck area was 13 ug/L. See Figure 22.

The samples collected for iron and manganese analysis from the seeps and lagoon were not filtered prior to analysis. These data were thus reported as total metals concentrations and are not directly comparable to the dissolved metals results reported for the groundwater. For Seeps A and B, the mean total iron concentrations were 14,000 and 13,000 ug/L, respectively, and the mean total manganese concentrations were 8,900 and 9,700 ug/L, respectively. The lagoon had a mean total iron concentration of 2,400 ug/L and a mean total manganese concentration of 590 ug/L.

Although the dissolved metals results for the groundwater cannot be directly compared to the total metals results for the seeps and lagoon, some comparison is possible. In general, a total metals concentration represents the maximum possible dissolved metals concentration. As such, it is unlikely that the high levels of dissolved manganese found in P-1D came directly from the lagoon where the mean total manganese concentration was just 29% of the mean dissolved manganese concentration in P-1D. Rather, it appears that the high dissolved manganese concentrations observed in P-1D may be unique to the groundwater in the vicinity of P-1D (see Analytical Variation and Lake Level subsection below for further discussion). The relatively high dissolved manganese concentrations in P-3, however, could be related to an impact from the lagoon. This impact could be related to a direct transfer of manganese from the lagoon to the groundwater, or it could be indicative of reducing conditions in the vadose zone (caused by the presence of downward flowing lagoon water).

The high total iron and manganese concentrations observed at the seeps is most likely related to oxidation and precipitation of these metals as the seep water moves from the ground to the surface. However, these concentrations may be significantly exaggerated due to gradual accumulation of iron and manganese precipitates at the seep outlets. As discussed above, the seep sampling procedures were modified beginning in March 1996 to reduce the amount of sediment collected in the sample bottles. It appears, however, that it may not be possible to account for this problem without some sort of field filtering procedure. A possible solution is recommended below.

According to a representative of the Lake Roosevelt National Recreation Area, there are numerous seeps along the Lake Roosevelt shoreline, but these are the only ones (of which he was aware) that have obvious iron and manganese staining at their outlets (Hebner, pers. comm.). This suggests that organic-laden water may be infiltrating in this area, leading to chemically-reduced conditions in the vadose zone and elevated dissolved iron and manganese in the groundwater. When this groundwater then discharges at the seeps, it is oxidized and accumulates as iron and manganese precipitates. The most-likely source for organic-laden water in this area is the unlined stormwater collection area approximately 150 meters northeast of the seeps (Figures 3 and 8). The high COD and T&L concentrations found at the seeps also support this hypothesis.

Given the overall lack of dissolved manganese data for the deep groundwater wells, no chemical distribution contour maps were prepared for dissolved manganese. The chemical distribution contour maps for dissolved iron in groundwater are shown in Appendix C, beginning on page 197. As shown in these figures, the distribution of dissolved iron in the groundwater was highly variable over the course of this study, but as shown in Table 8 this variation was not correlated with changes in lake elevation. In any event, all of the dissolved iron results were well below the Washington drinking water MCL of 300 ug/L.

Analytical Variation and Lake Levels

As discussed above, the majority of the analytical data sets showed no statistically-significant correlations with regard to changes in lake level (Table 8). Well P-1D was an exception to this, where significant correlations were observed for COD, chloride, TDS, T&L and dissolved manganese (Figures 23A-C). Negative lake-level correlations were found in the P-3D COD, TDS and T&L data, and the P-3D chloride data nearly showed a statistically-significant negative correlation (Table 8 and Figures 25A-D). Negative lake-level correlations were also found in the P-2D chloride data (Figure 24) and in the P-1 TDS data (Figure 26). In general, these correlations indicate that the groundwater beneath the lagoon area is not completely flushed to the lake during a single lake-level decline. The reason for the negative lake-level correlation in the P-1 TDS data is not entirely clear, but this could be related to vertical migration of the TDS plume in the vicinity of the P-1 wells.

The P-1D lake-level correlations for dissolved manganese terminated in the spring of 1996 when the largest lake draw-down occurred (Figure 23C). In March 1996, the lake elevations began separating from the P-1D groundwater elevations, and by May 1996 the lake elevation was 1.1 meters below the P-1D groundwater elevation (Figure 10). This was the lowest groundwater elevation observed in P-1D, and only 1.4 meters of P-1D's well screen were exposed to groundwater at this time (Tables 1 and 3 and Figure 7). As discussed above, Lake Roosevelt is presumed to normally provide the majority of groundwater in the lower coarse-grained aquifer, but during this extreme draw-down, most of the groundwater derived from Lake Roosevelt was flushed from around P-1D's well screen, thus increasing the proportion of land-derived groundwater. In addition to the physical flushing of the dissolved manganese contamination from the vicinity of P-1D, this event also appears to have created a less chemically-reducing environment in this area.

Temporal Trend Analysis

The results of the temporal trend analyses are shown in Table 9, and those data sets which displayed statistically-significant temporal trends are displayed graphically in Figures 27 through 34. As discussed above, the most dramatic temporal trend was observed in P-1D where the dissolved manganese concentrations fell a full order-of-magnitude at the beginning of 1996 (Figure 32A). In addition, all of the P-3 analytical parameters (except total phenolics) trended downward to varying degrees (Figures 27, 28A, 29A, 30B, 31 and 32B).

In Seep A, the COD concentrations have generally decreased through time, while chloride concentrations have generally increased through time. In the lagoon, several of the analytical parameters displayed statistically-significant temporal trends with COD, chloride, total phenolics, TDS, T&L and oil and grease decreasing through time, and pH gradually increasing through time (Figures 34A-E).

The decreasing constituent concentrations in the lagoon can be attributed to reductions in the volume of process water created at the plywood plant and the dilution of this process water with a relatively unchanged volume of cleaner water from the stormwater collection area. The decreasing constituent concentrations in the perched groundwater monitored at P-3 could be directly linked with the decreasing concentrations in the lagoon and/or to a gradual sedimentary sealing of the lagoon bottom.

CONCLUSIONS

From the lagoon area south to the P-4 wells, the occurrence and behavior of groundwater is controlled by Lake Roosevelt, and there is a very strong hydraulic connection between the groundwater and the lake in this area. There is very little groundwater gradient from the lagoon area south to the P-4 wells, and the groundwater elevations follow the changes in lake elevation very closely. More substantial groundwater gradients are observed among the log deck area wells, but these gradients appear to be at least partly related to the wells' relative responses to changes in lake level. The generally higher groundwater elevations observed in the log deck area appear to be related to additional groundwater entering the site from the hills to the east. The finer-grained sediments in the log deck area presumably retain this added head longer than the sediments in the lagoon area where the additional head would dissipate relatively quickly in the coarser-grained sediments. The P-3 and P-6 wells monitor groundwater zones which are largely independent of the lower aquifer and Lake Roosevelt. P-3 monitors a perched groundwater zone beneath the south end of the lagoon, while P-6 monitors a lens of silty sand surrounded by less transmissive silt and clay.

The direction of groundwater flow in the lagoon area is toward Lake Roosevelt when the lake is falling and away from Lake Roosevelt when the lake is rising. The groundwater beneath the log deck area also eventually moves into the lake, but the rate of discharge directly into the lake is presumably quite slow due to the fine-grained sediments between the log deck and Lake Roosevelt. Most of the groundwater discharge out of the log deck area likely moves north through the coarser-grained sediments of the lagoon area before entering Lake Roosevelt.

Due to the dynamic nature of the ground and surface water interaction, it is not possible to designate the wells at this site as *upgradient* and *downgradient* for the purpose of collecting *background* and *compliance* groundwater data. Although the log deck area wells are generally upgradient of the lagoon area wells, the majority of groundwater in the lower coarse-grained aquifer appears to be derived directly from Lake Roosevelt.

The seeps do not appear to be discharge locations for any of the water bearing zones monitored at this site. Rather, the seeps appear to discharge from a separate perched groundwater zone located near the lake shore. There are two likely sources for this perched groundwater: the unlined stormwater collection area located west of the sawmill, and Lake Roosevelt, when it is high enough to cover the seeps and recharge them. The stormwater collection area would contribute a relatively high organic load to any underlying perched groundwater, increasing the COD and T&L concentrations in the seep water, and leading to accumulation of iron and manganese precipitates at the seep outlets.

Over the course of this investigation, statistically-significant decreases were observed in several of the analytical data sets. Most notable among these was the dramatic decrease in the P-1D dissolved manganese concentrations. This decrease was concurrent with the large lake draw-down in the spring of 1996 where previously-contaminated groundwater appears to have been flushed from the vicinity of P-1D. In addition, most of the analytical parameters monitored at P-3 significantly declined, as did several of the lagoon analytical parameters.

With respect to COD, chloride, TDS, T&L and dissolved manganese, it appears that the lagoon has impacted the perched groundwater monitored at P-3. The lower aquifer in the lagoon area also appears to have been secondarily impacted to a lesser degree by the gradual seepage of these contaminants from the overlying perched groundwater. However, the thick layer of silt at the site appears to largely mitigate surface impacts on the lower aquifer in the lagoon area and on all of the groundwater beneath the log deck area. The activities in the log deck area do not appear to have significantly impacted the groundwater beneath the site.

The perched groundwater monitored at P-3 does not appear to discharge into Lake Roosevelt, and this groundwater is unlikely to directly impact the lake. The groundwater in the lower coarse-grained aquifer beneath the lagoon area is in direct communication with the lake, and over time, any contamination in this groundwater will eventually discharge into the lake. However, incomplete flushing is indicated in the lower coarse-grained aquifer, so several cycles of lake-elevation change are likely required to transport the contaminants into Lake Roosevelt.

RECOMMENDATIONS

Based on the above results, I suggest that the water quality monitoring program at this facility be modified as follows:

- Field filter all future seep and lagoon samples to provide dissolved (rather than total) iron and manganese data for the seeps and lagoon. This would allow for direct comparison with the dissolved iron and manganese data collected for the groundwater.

- Analyze future field blanks for TDS in addition to total phenolics. The total phenolics analysis does not allow for assessment of possible cross contamination between samples because phenolics are generally not found in the samples. Detectable TDS concentrations are always found to some degree in all of the samples.

- Only test the groundwater and seep samples for total phenolics once per year. As discussed above, no reliable evidence of phenolics contamination in groundwater has been found at this site. The lagoon should continue to be analyzed for phenolics on a quarterly basis, and it may be advisable to continue to test P-3 for phenolics on a quarterly basis to allow for early detection of phenolics in groundwater if it should occur in the future.

- Eliminate the monthly sampling requirement, and simply sample all of the monitoring wells, the seeps and the lagoon on a quarterly basis. The current protocol of sampling the "downgradient" wells on a monthly basis is somewhat baseless due to the lack of consistent groundwater gradients at the site. Furthermore, substantial analytical variation has generally not been observed on a monthly basis.

- To determine if Lake Roosevelt has been significantly impacted by activities at this site, it would be useful to collect upstream and downstream water samples directly from the lake. These samples should be analyzed for the same parameters as the groundwater samples.

- To determine if a second perched groundwater zone exists near the seeps and to allow for direct assessment of the quality of this groundwater, an additional monitoring well should be installed between the stormwater collection area and the seeps. If the stormwater collection area is confirmed to be the primary source for the contaminants discharging at the seeps, the stormwater collection area should be lined.

- Although some groundwater contamination from the lagoon is indicated, this contamination does not appear to be significant enough to warrant lining of the lagoon.

- Care should be taken when the lagoon is dredged to avoid disturbing the partial sedimentary seal which appears to have formed on the bottom of the lagoon.

- If the WDOE were to require collection of actual background water quality data, it would be necessary to install two or more wells east of the site (to assess the land-derived groundwater) and to collect Lake Roosevelt samples upstream of the site. It would then be necessary to quantify the relative contributions of each of these groundwater sources, and to characterize the natural water-chemistry changes which occur as the lake water enters the groundwater system. However, given the existing extent of groundwater contamination, the cost and complexity of such additional work is probably not justified.

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Tables

Table 1. Groundwater Monitoring Well Construction Data

Monitoring Well	Elevation Data		Well Construction Details						
	Top of Casing [1]	Grade [2]	Total Depth [3]	Cased Interval [4]	Screened Interval	Sealed Interval [5]	Filter Pack Interval [6]	Screen Slot Size	Casing Diameter
	------ meters ------		------ meters below ground surface ------					---- centimeters ----	
P-1	405.83	405.11	19.81	+0.73 - 19.81	16.61 - 19.66	13.59 - 15.73	15.73 - 19.81	0.051	5.1
P-1D	405.65	405.02	31.70	+0.64 - 31.70	27.04 - 31.61	25.30 - 26.21	26.21 - 31.70	0.051	5.1
P-2	399.15	398.39	12.65	+0.76 - 12.65	9.51 - 12.56	7.13 - 8.66	8.66 - 12.68	0.051	5.1
P-2D	398.74	398.31	22.86	+0.43 - 22.86	18.20 - 22.77	16.46 - 17.37	17.37 - 22.86	0.051	5.1
P-3	401.62	401.69	13.20	0.06 - 13.50	10.06 - 13.11	8.53 - 9.45	9.45 - 13.41	0.051	5.1
P-3D	401.37	401.49	27.74	0.12 - 27.74	23.07 - 27.65	21.24 - 22.16	22.16 - 27.74	0.051	5.1
P-4	403.94	403.08	16.86	+0.85 - 16.86	13.72 - 16.76	9.75 - 12.50	12.50 - 16.92	0.025	5.1
P-4D	403.60	403.02	27.43	+0.58 - 27.43	22.77 - 27.34	21.03 - 21.95	21.95 - 27.43	0.051	5.1
P-5	403.17	402.39	21.49	+0.76 - 21.49	18.29 - 21.34	15.85 - 17.37	17.37 - 21.49	0.025	5.1
P-6	402.58	402.11	22.56	+0.46 - 22.56	19.35 - 22.40	16.15 - 18.07	18.07 - 22.56	0.025	5.1
P-7	402.91	402.26	25.60	+0.64 - 25.60	20.94 - 25.51	19.20 - 20.12	20.12 - 25.60	0.025	5.1
P-8	404.25	403.59	31.39	+0.67 - 31.39	26.73 - 31.30	25.30 - 25.91	25.91 - 31.39	0.025	5.1

Notes

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[1] Top of Casing = Top of PVC casing measured by a licensed surveyor to nearest 0.01 feet (0.003 meters) above mean sea level.

[2] Grade = Surface elevation measured by a licensed surveyor to nearest 0.01 feet (0.003 meters) from reference nail in well platform.

[3] Total Depth = Depth of well below ground surface.

[4] When a "+" preceeds the first number of the cased interval-range, the top-of-casing height above grade is indicated; otherwise, the first number indicates the top-of-casing depth below grade.

[5] Sealed Interval = Location of bentonite seal.

[6] Filter Pack Interval = Location of CSSI filter-sand pack.

Table 2. Analytical Testing Parameters and Methods

Constituent	EPA Method	Groundwater Wells	Seeps	Lagoon
Chemical Oxygen Demand (COD)	410.2	X	X	X
Chloride	300.0	X	X	X
Total Phenolics	420.1	X	X	X
Total Dissolved Solids (TDS)	160.1	X	X	X
Total Suspended Solids (TSS)	160.2			X
Tannin and Lignin	5550B	X	X	X
Dissolved Iron and Manganese	6010A	X		
Total Iron and Manganese	6010A		X	X
pH	9040			X
Oil and Grease	413.1			X
Total Recoverable Petroleum Hydrocarbons (TRPH)	418.1			X
Formaldehyde	D-19			X

Table 3. Groundwater Elevation Data -- meters above mean sea level (1929 Coastal & Geodetic datum)

Date	Lake Roosevelt[1]	LAGOON AREA WELLS							LOG DECK AREA WELLS				
		P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-6	P-7
4/19/94	384.93	dry[2]	385.08	dry	385.10	391.04	385.06	385.09	dry	385.08	388.69	394.35	386.78
5/17/94	390.43	389.76	389.77	389.78	389.77	391.07	389.78	389.77	389.83	389.84	390.24	394.18	390.68
6/21/94	388.16	388.32	388.32	388.32	388.33	391.09	388.31	388.32	388.33	388.32	390.26	394.18	389.58
7/18/94	388.41	388.25	388.26	388.26	388.27	391.00	388.25	388.26	388.28	388.28	390.03	394.24	389.48
8/10/94	388.54	388.28	388.29	388.30	388.31	390.96	388.29	388.29	388.32	388.32	389.89	394.25	389.53
9/6/94	389.59	389.08	389.09	389.10	389.09	391.02	389.08	389.09	389.10	389.10	390.37	394.26	390.11
10/12/94	392.15	391.88	391.89	391.90	391.90	391.28	391.89	391.88	391.93	391.92	391.95	394.28	392.39
11/7/94	391.27	391.08	391.09	391.10	391.09	391.53	391.09	391.08	391.12	391.12	391.96	394.32	391.70
12/5/94	391.30	391.22	391.23	391.16	391.23	391.56	391.22	391.22	391.27	391.24	391.97	394.35	391.73
1/3/95	390.78	391.08	391.09	391.09	391.08	frozen[3]	frozen	391.08	391.07	391.06	391.94	394.39	391.63
2/7/95	387.77	388.07	388.07	388.08	388.08	391.40	388.06	388.08	388.08	388.06	390.37	394.44	389.36
3/8/95	381.52	dry	382.37	dry	382.37	391.14	382.33	382.38	dry	382.30	387.66	394.44	384.76
4/11/95	385.43	dry	385.18	dry	385.20	391.09	385.18	385.19	dry	385.23	387.74	394.30	387.16
5/9/95	381.93	dry	382.45	dry	382.48	390.99	382.42	382.47	dry	382.43	386.96	394.07	384.80
6/8/95	389.96	388.03	388.03	388.04	388.05	390.97	388.08	388.07	388.17	388.22	388.27	393.87	389.55
7/11/95	392.40	392.13	392.13	392.14	392.13	391.47	392.14	392.13	392.19	392.18	391.59	393.81	392.60
8/9/95	390.08	390.08	390.09	390.10	390.10	391.62	390.10	390.09	390.12	390.11	391.37	393.88	391.04
9/6/95	390.17	390.01	390.02	390.00	390.00	391.51	389.99	389.99	390.01	390.01	391.19	393.95	390.91
10/16/95	391.26	391.31	391.31	391.31	391.31	391.83	391.30	391.35	391.32	391.31	392.27	394.05	391.94
11/6/95	390.78	390.80	390.80	390.81	390.81	391.78	390.79	390.80	390.81	390.80	392.03	394.10	391.51
12/5/95	392.47	392.35	392.36	392.37	392.37	392.05	392.37	392.36	392.40	392.39	392.70	394.16	392.76
1/8/96	391.09	391.10	391.10	391.11	391.11	392.13	391.10	391.10	391.12	391.11	392.23	394.22	391.80
2/6/96	388.65	388.82	388.83	388.84	388.84	frozen	frozen	388.84	388.84	388.83	391.07	394.27	389.99
3/6/96	386.36	387.53	387.53	387.51	387.52	391.63	387.47	387.50	387.50	387.50	390.43	394.31	388.87
4/9/96	376.34	dry	378.22	dry	378.23	391.36	378.15	378.27	dry	378.16	386.56	394.30	381.52
5/7/96	373.70	dry	374.82	dry	dry	391.28	374.78	375.11	dry	dry	384.99	393.73	379.34
6/4/96	379.81	dry	378.11	dry	378.13	391.24	378.19	378.04	dry	378.17	384.43	387.60	382.38
7/10/96	392.23	391.57	391.57	391.58	391.58	391.35	391.60	391.56	391.66	391.66	389.13	388.50	391.99
8/1/96	391.71	391.81	391.82	391.83	391.82	391.77	391.81	391.81	391.85	391.83	391.08	390.99	392.33
9/11/96	390.04	390.13	390.14	390.15	390.14	391.73	390.13	390.14	390.17	390.15	391.25	391.37	391.03
10/8/96	390.97	390.74	390.75	390.75	390.75	391.60	390.75	390.74	390.78	390.77	391.42	391.26	391.47
11/6/96	391.03	391.10	391.10	391.10	391.10	391.73	391.10	391.09	391.12	391.11	391.85	391.63	391.73
12/11/96	389.99	389.98	389.98	389.99	390.00	391.70	389.98	389.98	390.00	389.99	391.40	391.70	390.88

Notes

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[1] Surface elevation of Lake Roosevelt. Lake elevations corrected to 1929 Coastal & Geodetic datum in Kettle Falls; reduced by 0.55 meters from reported elevations at Grand Coulee Dam.

[2] Well dry, groundwater elevation data not available.

[3] Flush-mounted wells boxes filled with ice. Well casings inaccessible.

Table 4A. Chemical Oxygen Demand - Groundwater Sampling Analytical Results (ND-adjusted data) -- mg/L

	LAGOON AREA							LOG DECK AREA			
Date	**P-1**	**P-1D**	**P-2**	**P-2D**	**P-3**	**P-3D**	**P-8**	**P-4**	**P-4D**	**P-5**	**P-7**
4/20/94				17			5		8		
5/17/94	27	44	22	15				8	*0*		
6/21/94	20	39		12	54	11	5		*0*	34	18
7/18/94	32	30		5					5		
8/10/94	22	23		17					*0*		
9/7/94	41	7		8	65	15	7		6	23	16
10/12/94	13	38	10	*2.5*				10	*0*		
11/11/94	*2.5*	40		*2.5*				*0*	*0*		
12/5/94	17	43		5	65	6	*0*	*0*	*0*	22	19
1/3/95	*2.5*	65		*2.5*				*0*	*0*		
2/7/95	8	61			73	8	*0*	10	*0*		
3/9/95		14		16	72	31	11		8	15	29
4/11/95		34			75	16			*0*		
5/8/95		5			76	21			*0*		
6/8/95	25	21	*2.5*	13	78	11	*0*	*0*	*0*	*0*	6
7/11/95	20	40			81	13		7	*0*		
8/9/95	16	39			78	10		5	8		
9/7/95	15	45	13	13	71		*0*	*0*	*0*	6	43
10/16/95	10	40			51	11		5	*0*		
11/9/95	9	49			54	16		5	8		
12/5/95	6	57	12	12	52	16	*0*	6	*0*	*0*	7
1/8/96	17	51			37	7		*0*	*0*		
2/7/96	15							*0*	*0*		
3/6/96	7	48	11	9	42	9	7	6	8	*0*	15
4/9/96		5			45	39			*0*		
5/7/96		*2.5*			50						
6/7/96		*2.5*		7	40	17	*0*		*0*	*0*	*2.5*
7/10/96	8	22			39	19		14	11	13	
8/1/96	18	32			44	16				12	
9/12/96	13	25	*2.5*	6	38	9	*0*	*0*	*0*	*0*	*2.5*
10/9/96	23	31			31	8		*0*	*0*		
11/6/96	22	29			23	13		7	*0*		
12/11/96	7	34	*2.5*	7	22	12	*0*	*0*	*0*	*0*	6
% ND	8%	6%	38%	17%	0%	0%	62%	48%	74%	46%	18%
ND action / adjustment	replace w/ 1/2 ND	replace w/ 1/2 ND	Cohen	Cohen	none	none	Aitchison	Aitchison	Aitchison	Aitchison	Cohen
mean_c[1]	16.0	32.8	7.8	9.5	54.2	14.5	2.7	4.0	2.0	9.6	13.4
stdev_c[2]	9.2	17.1	8.5	5.1	18.1	7.7	3.8	4.3	3.5	11.3	14.1
count[3]	26	31	8	18	25	23	13	21	31	13	11

Notes

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[1] mean_c = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[2] stdev_c = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[3] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 5 mg/L.

Blank cell indicates that no sample was collected.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.
- If data set has 16% to 50% NDs but is not normally distributed, use Aitchison's adjustment in lieu of Cohen's adjustment.

No applicable Washington State maximum contaminant level for this parameter (WAC 246-290-310).

Table 4B. Chloride - Groundwater Sampling Analytical Results (ND-adjusted data) -- mg/L

	LAGOON AREA							LOG DECK AREA			
Date	**P-1**	**P-1D**	**P-2**	**P-2D**	**P-3**	**P-3D**	**P-8**	**P-4**	**P-4D**	**P-5**	**P-7**
4/20/94				140			5.2		14		
5/17/94	110	120	38	140				24	11		
6/21/94	120	120		140	320	160	36		12	0.9	7.6
7/18/94	120	100		140					10		
8/10/94	140	100		140					9.8		
9/7/94	140	100		140	450	160	41		10	1	7.4
10/12/94	65	160	41	120				24	9.5		
11/11/94	51	180		140				23	11		
12/5/94	40	170		140	430	140	47	21	9.7	1.1	7.1
1/3/95	43	170		140				22	12		
2/7/95	67	130			400	150	25	23	13		
3/9/95		46		170	430	170	5.8		14	0.8	7.6
4/11/95		110			480	170			11		
5/8/95		43			490	180			13		
6/8/95	12	81	32	160	510	160	41	18	11	0.9	8.3
7/11/95	100	110			520	160		19	12		
8/9/95	110	150			380	180		13	13		
9/7/95	96	150	6.1	130	480	160	46	17	14	0.9	8.9
10/16/95	81	190			390	160		19	14		
11/9/95	77	180			450	150		18	15		
12/5/95	46	230	35	120	330	160	46	18	13	0.9	8.9
1/8/96	60	210			340	160		16	15		
2/7/96	75							20	14		
3/6/96	68	82	25	110	240	130	37	22	14	0.8	7.1
4/9/96		37			300	170			14		
5/7/96		43			310						
6/7/96		40		170	220	170	57		14	1.3	8.2
7/10/96	50	71			130	150		15	8.9	0.9	
8/1/96	80	110			150	150				1.0	
9/12/96	75	120	40	140	160	130	56	13	12	0.7	7.6
10/9/96	120	160			160	150		16	14		
11/6/96	92	180			160	180		16	15		
12/11/96	50	170	45	170	130	170	62	15	12	1.3	8
% ND	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
ND action / adjustment	none	none	none	none	none	none	none	none	none	none	none
mean$_c$[1]	80.3	124.6	32.8	141.7	334.4	159.2	38.8	18.7	12.4	1.0	7.9
stdev$_c$[2]	32.9	53.3	12.4	16.9	132.2	13.8	17.7	3.5	1.8	0.2	0.6
count[3]	26	31	8	18	25	24	13	21	31	13	11

Notes

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[1] mean$_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[2] stdev$_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[3] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 0.2 mg/L.

Blank cell indicates that no sample was collected.

▨ = Above Washington State maximum contaminant level: 250 mg/L (WAC 246-290-310).

Table 4C-1. Total Phenolics - Groundwater Sampling Analytical Results (ND-adjusted data) -- mg/L

Date	LAGOON AREA							LOG DECK AREA			
	P-1	**P-1D**	**P-2**	**P-2D**	**P-3**	**P-3D**	**P-8**	**P-4**	**P-4D**	**P-5**	**P-7**
4/20/94				*0.00*			*0.00*		*0.00*		
5/17/94	*0.00*	*0.00*	0.01	*0.00*				0.01	*0.00*		
6/21/94	*0.00*	*0.00*		*0.00*	0.02[1]	*0.00*	0.03[1]		*0.00*	0.02[1]	0.04[1]
7/18/94	*0.00*	*0.00*		*0.00*					*0.00*		
8/10/94	0.02	*0.00*		*0.00*					*0.00*		
9/7/94	*0.00*	*0.02*		*0.00*	*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*
10/12/94	*0.00*	*0.00*	*0.00*	*0.00*				*0.00*	*0.00*		
11/11/94	*0.00*	*0.00*		*0.00*				*0.00*	*0.00*		
12/5/94	*0.00*	*0.00*		*0.01*	0.19[1]	*0.00*	0.19[1]	*0.01*	0.15[1]	*0.00*	*0.00*
1/3/95	*0.00*	0.40[1]		0.10[1]				0.10[1]	*0.00*		
2/7/95	*0.00*	*0.00*			*0.00*	*0.00*	*0.00*	*0.00*	*0.00*		
3/9/95		*0.00*		*0.00*	0.01	0.02[1]	*0.00*		*0.00*	*0.00*	*0.00*
4/11/95		*0.00*		*0.00*	*0.00*	*0.00*			*0.00*		
5/8/95		*0.00*			*0.00*	*0.00*			*0.00*		
6/8/95	0.02[1]	0.02[1]	0.01	0.01	*0.01*	*0.00*	0.02[1]	*0.00*	*0.00*	0.01	0.01
7/11/95	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
8/9/95	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
9/7/95	*0.00*	0.01	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10/16/95	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		*0.00*
11/9/95	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
12/5/95	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
1/8/96	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
2/7/96	*0.00*							*0.00*	*0.00*		
3/6/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
4/9/96		*0.00*			*0.00*	*0.00*			*0.00*		
5/7/96		*0.00*			*0.00*						
6/7/96		*0.01*		0.01	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
7/10/96	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*	*0.00*	
8/1/96	*0.00*	*0.00*			*0.00*	*0.00*				*0.00*	
9/12/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10/9/96	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
11/6/96	*0.00*	*0.00*			*0.00*	*0.00*		*0.00*	*0.00*		
12/11/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
% ND	92%	90%	75%	83%	91%	100%	100%	90%	100%	92%	91%
ND action / adjustment	replace ND w/ 0	Aitchison	Aitchison	Aitchison	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0
mean$_c$[2]	0.001	0.001	0.003	0.002	0.001	0.000	0.000	0.001	0.000	0.001	0.001
stdev$_c$[3]	0.004	0.004	0.005	0.004	0.003	0.000	0.000	0.003	0.000	0.003	0.003
count[4]	25	29	8	18	23	23	10	21	30	12	11

Notes

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[1] Questionable result; phenols also found in some of the field blanks; laboratory contamination suspected.

[2] mean$_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[3] stdev$_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[4] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 0.01 mg/L.

Blank cell indicates that no sample was collected.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.

No applicable Washington State maximum contaminant level (WAC 246-290-310).

Table 4C-2. Total Phenolics - Field Blank Analytical Results (ND-adjusted data) -- mg/L

Date	FB1	FB2	FB3	FB4	FB5	FB6
6/21/94	0.05 [1]	0.06 [1]	0.03 [1]	0.02 [1]	0.10 [1]	
7/18/94	*0.00*	*0.00*				
8/10/94	*0.00*	0.01 [1]				
9/7/94	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
10/12/94	*0.00*	*0.00*	*0.00*			
11/11/94	*0.00*	*0.00*	*0.00*			
12/5/94	*0.00*	*0.00*	*0.00*	*0.00*		
1/3/95	0.10 [1]	*0.00*	*0.00*			
2/7/95	*0.00*	*0.00*	*0.00*			
3/9/95	0.03 [1]	0.06 [1]	0.01 [1]	0.03 [1]	0.03 [1]	0.01 [1]
4/11/95	*0.00*					
5/8/95	*0.00*	*0.00*	*0.00*	*0.00*		
6/12/95	0.01 [1]	0.01 [1]	0.01 [1]	*0.00*	*0.00*	*0.00*
8/9/95	*0.00*	*0.00*	*0.00*			
9/7/95	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10/16/95	*0.00*					
11/9/95	*0.00*	*0.00*	*0.00*	*0.00*		
12/5/95	*0.00*	0.02 [1]	*0.00*	*0.00*	*0.00*	*0.00*
1/8/96	*0.00*	*0.00*	*0.00*	*0.00*		
2/7/96	*0.00*	*0.00*	0.06 [1]			
3/6/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
4/9/96	*0.00*					
5/7/96	*0.00*					
6/7/96	*0.00*	*0.00*	*0.00*	0.03 [1]	0.02 [1]	
7/10/96	*0.00*					
8/1/96	0.01 [1]	0.01 [1]				
9/12/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
10/9/96	*0.00*	*0.00*	*0.00*			
11/6/96	*0.00*					
12/11/96	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
% ND	100%	100%	100%	100%	100%	100%
ND action / adjustment	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0
mean_c [2]	0.000	0.000	0.000	0.000	0.000	0.000
stdev_c [3]	0.000	0.000	0.000	0.000	0.000	0.000
count [4]	25	18	17	11	7	4

Notes

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[1] Questionable result; laboratory contamination suspected.

[2] mean_c = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[3] stdev_c = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[4] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 0.01 mg/L.

Number of field blanks created determined by number of coolers required to ship samples to laboratory.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.

No applicable Washington State maximum contaminant level for this parameter (WAC 246-290-310).

Table 4D. Total Dissolved Solids - Groundwater Sampling Analytical Results (ND-adjusted data) -- mg/L

	LAGOON AREA							LOG DECK AREA			
Date	P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-7
4/20/94				829			256		444		
5/17/94	794	775	520	734				450	462		
6/21/94	831	765		816	1550	850	426		420	273	389
7/18/94	880	734		799					423		
8/10/94	912	750		828					458		
9/7/94	910	737		837	1880	910	496		457	284	421
10/12/94	668	897	513	701				478	440		
11/11/94	564	930		733				437	439		
12/5/94	537	900		760	1840	787	476	476	451	277	406
1/3/95	840	838		765				462	426		
2/7/95	677	762			1680	790	361	470	425		
3/9/95		490		784	1540	834	246		404	252	346
4/11/95		674			1960	859			420		
5/8/95		469			1720	931			420		
6/8/95	749	680	427	873	1590	856	438	459	446	253	394
7/11/95	794	835			2040	903		493	485		
8/9/95	814	902			1900	822		463	428		
9/7/95	757	866	243	1230	1830	856	479	518	455	262	326
10/16/95	648	953			1510	808		467	418		
11/9/95	695	973			1500	833		464	413		
12/5/95	538	1070	511	788	1390	810	477	459	422	248	413
1/8/96	654	1060			1410	808		477	431		
2/7/96	727							510	442		
3/6/96	702	665	500	841	1460	808	373	504	429	250	357
4/9/96		519			1460	1010			427		
5/7/96		558			1450						
6/7/96		576		916	1250	968	493		463	265	412
7/10/96	637	689			958	925		499	475	274	
8/1/96	726	808			1010	878				273	
9/12/96	736	834	558	872	1030	826	519	486	455	266	402
10/9/96	810	904			940	876		517	480		
11/6/96	736	958			822	906		495	477		
12/11/96	668	920	577	852	786	960	499	519	484	298	437
% ND	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
ND action / adjustment	none	none	none	none	none	none	none	none	none	none	none
$mean_c$[1]	730.9	790.0	481.1	831.0	1460.2	867.3	426.1	481.1	442.5	267.3	391.2
$stdev_c$[2]	103.6	159.6	105.9	114.0	365.8	60.5	91.2	23.8	22.7	14.6	34.2
count[3]	26	31	8	18	25	24	13	21	31	13	11

Notes

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[1] $mean_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[2] $stdev_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[3] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 5 mg/L.

Blank cell indicates that no sample was collected.

▨ = Above Washington State maximum contaminant level: 500 mg/L (WAC 246-290-310).

Table 4E. Tannin and Lignin - Groundwater Sampling Analytical Results (ND-adjusted data) -- mg/L

Date	LAGOON AREA							LOG DECK AREA			
	P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-7
4/20/94				*0.0*			*0.0*		*0.0*		
5/17/94	0.4	0.9	*0.0*	*0.0*				*0.0*	*0.0*		
6/21/94	0.3	1.1		*0.0*	0.5	*0.0*	*0.0*		*0.0*	0.2	*0.0*
7/18/94	0.4	0.8		*0.0*					*0.0*		
8/10/94	0.7	0.8		0.3					0.3		
9/7/94	0.6	0.4		*0.0*	0.8	*0.0*	*0.0*		*0.0*	*0.0*	*0.0*
10/12/94	0.3	1.1	*0.0*	*0.0*				*0.0*	*0.0*		
11/11/94	*0.0*	1.2		*0.0*				*0.0*	*0.0*		
12/5/94	*0.0*	1.2		*0.0*	0.7	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
1/3/95	0.2	4.4		0.2				0.2	*0.0*		
2/7/95	0.2	2.5			0.7	*0.0*	*0.0*	*0.0*	*0.0*		
3/9/95		0.5		0.3	0.8	0.6	0.3		0.3	0.3	0.5
4/11/95		0.8			0.9	0.3			*0.0*		
5/8/95		0.2			0.8	0.3			*0.0*		
6/8/95	0.6	0.7	*0.0*	*0.0*	0.9	0.2	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
7/11/95	0.3	1.0			0.9	0.2		0.2	*0.0*		
8/9/95	0.5	1.1			0.9	0.3		*0.0*	*0.0*		
9/7/95	0.2	1.2	*0.0*	*0.0*	0.6	*0.0*	0.2	*0.0*	0.3	0.2	0.6
10/16/95	0.4	1.3			0.6	0.3		0.4	0.5		
11/9/95	*0.0*	1.2			0.5	0.4		*0.0*	*0.0*		
12/5/95	*0.0*	1.1	*0.0*	*0.0*	0.4	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
1/8/96	*0.0*	1.6			0.4	*0.0*		*0.0*	*0.0*		
2/7/96	*0.0*							*0.0*	*0.0*		
3/6/96	*0.0*	1.1	*0.0*	*0.0*	0.4	*0.0*	*0.0*	0.6	*0.0*	*0.0*	*0.0*
4/9/96		*0.1*			0.5	0.6			*0.0*		
5/7/96		*0.1*			0.4						
6/7/96		*0.1*		*0.0*	0.5	0.2	*0.0*		*0.0*	*0.0*	*0.0*
7/10/96	*0.0*	0.4			0.5	*0.0*		*0.0*	*0.0*	*0.0*	
8/1/96	*0.0*	0.3			0.5	*0.0*				*0.0*	
9/12/96	0.2	0.5	*0.0*	*0.0*	0.5	*0.0*	*0.0*	*0.0*	0.7	*0.0*	0.8
10/9/96	0.4	0.5			0.5	0.2		*0.0*	*0.0*		
11/6/96	0.3	0.4			0.4	0.2		*0.0*	*0.0*		
12/11/96	*0.0*	0.5	*0.0*	*0.0*	0.3	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
% ND	38%	10%	100%	83%	0%	50%	85%	81%	84%	77%	73%
ND action / adjustment	Aitchison	replace w/ 1/2 ND	replace ND w/ 0	Aitchison	none	Aitchison	Aitchison	Aitchison	Aitchison	Aitchison	Aitchison
mean$_c$[1]	0.23	0.94	0.00	0.04	0.60	0.16	0.04	0.07	0.07	0.05	0.17
stdev$_c$[2]	0.22	0.82	0.00	0.10	0.19	0.19	0.10	0.16	0.17	0.11	0.30
count[3]	26	31	8	18	25	24	13	21	31	13	11

Notes

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[1] mean$_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[2] stdev$_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[3] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 0.2 mg/L.

Blank cell indicates that no sample was collected.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.
- If data set has 16% to 50% NDs but is not normally distributed, use Aitchison's adjustment in lieu of Cohen's adjustment.

No applicable Washington State maximum contaminant level (WAC 246-290-310).

Table 4F. Dissolved Iron - Groundwater Sampling Analytical Results (ND-adjusted data) -- ug/L

Date	LAGOON AREA							LOG DECK AREA			
	P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-7
4/20/94				78[1]			53[1]		112[1]		
5/17/94	85	29	28	84				21	41		
6/21/94	51	34		40	46	40	28		68	53	36
7/18/94	41	37		35					42		
8/10/94	*10*	*10*		52					44		
9/7/94	34	39		54	55	48	36		48	22	27
10/12/94	31	39	31	34				50	34		
11/11/94	67	114		68				75	60		
12/5/94	33	49		41	57	42	30	41	36	22	26
1/3/95	22	49		21				*10*	*10*		
2/7/95	31	60			47	33	149[2]	165	32		
3/9/95		28		43	56	42	32		52	26	28
4/11/95		33			56	64			94		
5/8/95		26			57	46			39		
6/8/95	23	*10*	*10*	37	42	24	40	431[2]	26	*10*	50
7/11/95	49	298[2]			60	43		184	101		
8/9/95	30	31			50	40		57	31		
9/7/95	32	36	31	7600[2]	55	36	30	33	25	23	158
10/16/95	37	47			54	41		167	42		
11/9/95	55	42			50	36		42	35		
12/5/95	26	107	30	33	39	29	24	24	22	*10*	766[2]
1/8/96	44	47			37	105		79	112		
2/7/96	28							234	36		
3/6/96	49	33	30	1490[2]	45	39	44	51	46	49	59
4/9/96		27			43	36			158		
5/7/96		36			45						
6/7/96		34		56	44	44	35		82	68	34
7/10/96	42	36			35	38		72	224	30	
8/1/96	33	30			28	49				51	
9/12/96	37	43	47	92	44	51	70	137	138	34	124
10/9/96	44	41			43	38		133	135		
11/6/96	36	42			34	48		137	101		
12/11/96	55	42	552[2]	80	27	38	45	64	48	271[2]	35
% ND	4%	7%	14%	0%	0%	0%	0%	5%	3%	17%	0%
ND action / adjustment	replace w/ 1/2 ND	replace w/ 1/2 ND	replace w/ 1/2 ND	none	none	none	none	replace w/ 1/2 ND	replace w/ 1/2 ND	Cohen	none
mean$_c$[3]	39.4	41.0	29.6	51.3	46.0	43.8	37.6	88.8	65.4	33.5	57.7
stdev$_c$[4]	15.3	21.5	10.8	21.0	9.2	15.3	12.6	63.4	48.3	18.5	45.8
count[5]	26	30	7	15	25	24	11	20	30	12	10

Notes

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[1] Samples collected on 4/20/94 not field filtered; analysis performed on unpreserved, lab filtered sample water on 5/27/94.

[2] Anomalous result may have been caused by a field-filtering failure where undissolved metals may have passed into sample container.

[3] mean$_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[4] stdev$_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[5] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 20 ug/L.

Blank cell indicates that no sample was collected. All samples field-filtered except as noted above.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.

▨ = Above Washington State maximum contaminant level: 300 ug/L (WAC 246-290-310).

Table 4G. Dissolved Manganese - Groundwater Sampling Analytical Results (ND-adjusted data) -- ug/L

Date	LAGOON AREA							LOG DECK AREA			
	P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-7
4/20/94				<5[1]			<5[1]		10[1]		
5/17/94	11	1720	89	*0*				*0*	*0*		
6/21/94	9	2230		*0*	170	*0*	*0*		*0*	44	59
7/18/94	54	1310		*0*					*0*		
8/10/94	201	1120		*0*					*0*		
9/7/94	192	909		*0*	224	*0*	*0*		*0*	50	38
10/12/94	92	2720	220	*0*				*0*	*0*		
11/11/94	8	2950		*0*				*0*	*0*		
12/5/94	*0*	2880		*0*	193	*0*	*0*	*0*	*0*	25	55
1/3/95	*0*	7880		*0*				*0*	*0*		
2/7/95	*0*	4190			178	*0*	*0*	*0*	*0*		
3/9/95		1430		*0*	191	*0*	*0*		*0*	17	12
4/11/95		1510			203	*0*			*0*		
5/8/95		557			254	*0*			*0*		
6/8/95	*0*	1480	*0*	9	256	*0*	*0*	7[2]	*0*	20	50
7/11/95	*0*	2100			222	*0*		*0*	*0*		
8/9/95	*0*	2250			161	*0*		*0*	*0*		
9/7/95	*0*	3640	6	174[2]	186	*0*	*0*	*0*	*0*	13	20
10/16/95	*0*	4850			165	*0*		*0*	*0*		
11/9/95	*0*	4750			167	*0*		*0*	*0*		
12/5/95	*0*	5160	11	*0*	142	*0*	*0*	*0*	*0*	17	34
1/8/96	*0*	4730			130	*0*		*0*	*0*		
2/7/96	*0*							*0*	*0*		
3/6/96	*0*	1520	*0*	35[2]	170	*0*	*0*	*0*	*0*	19	14
4/9/96		117			157	*0*			*0*		
5/7/96		*2.5*			154						
6/7/96		13		*0*	144	*0*	*0*		*0*	14	6
7/10/96	*0*	146			100	*0*		*0*	*0*	14	
8/1/96	*0*	114			68	*0*				16	
9/12/96	*0*	84	*0*	*0*	76	*0*	*0*	*0*	*0*	14	11
10/9/96	*0*	76			105	*0*		*0*	*0*		
11/6/96	*0*	90			92	*0*		*0*	*0*		
12/11/96	*0*	119	8	*0*	84	*0*	*0*	*0*	*0*	22	10
% ND	73%	3%	38%	93%	0%	100%	100%	100%	100%	0%	0%
ND action / adjustment	Aitchison	replace w/ 1/2 ND	Aitchison	replace ND w/ 0	none	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	replace ND w/ 0	none	none
mean$_c$[3]	21.8	2021	41.8	0.6	159.7	0.0	0.0	0.0	0.0	21.9	28.1
stdev$_c$[4]	55.3	1968	78.0	2.3	52.1	0.0	0.0	0.0	0.0	11.7	19.8
count[5]	26	31	8	15	25	24	12	20	30	13	11

Notes

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[1] Samples collected on 4/20/94 not field filtered; analysis performed on unpreserved, <u>lab filtered</u> sample water on 5/27/94.

[2] Anomalous result may have been caused by a field-filtering failure where undissolved metals may have passed into sample container.

[3] mean$_c$ = arithmetic mean of the sample set, corrected using the appropriate "ND action/adjustment."

[4] stdev$_c$ = standard deviation of the sample set, corrected using the appropriate "ND action/adjustment."

[5] count = number of samples used to perform statistical calculations.

Method reporting limit (MRL) = 5 ug/L.

Blank cell indicates that no sample was collected. All samples field-filtered except as noted above.

Italicized results originally reported as less-than the MRL; less-than values replaced per the appropriate "ND action/adjustment."

- If < 15% NDs, replace NDs with 1/2 MRL. If 16% to 50% NDs, use Cohen's adjustment & replace NDs with 1/2 MRL.
- If 51% to 90% NDs, use Aitchison's adjustment & replace NDs with 0. If > 90% NDs, replace NDs with 0.
- If data set has 16% to 50% NDs but is not normally distributed, use Aitchison's adjustment in lieu of Cohen's adjustment.

▨ = Above Washington State maximum contaminant level: 50 ug/L (WAC 246-290-310).

Table 5A. Seep A Analytical Results (ND-adjusted data)

Date	------------------ mg/L ------------------					--- ug/L ---	
	COD	**Cl**	**Phenol**	**TDS**	**T&L**	**Total Fe**	**Total Mn**
5/3/94	45	4.5	*0.00*	576	2.1	10200	7380
6/21/94	59	5.9	0.04[6]	609	2.5	14700	8810
9/7/94	63	5.8	*0.00*	662	2.3	14000	9240
12/5/94	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged
3/9/95	32	11.0	*0.00*	473	14.3	17400	7520
5/9/95	45	10.0	*0.00*	579	2.1	10200	8820
9/6/95	55	8.9	*0.00*	655	1.9	22800	9570
12/5/95	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged
3/7/96	43	20.0	*0.00*	697	1.7	14000	10600
5/7/96	49	19.0	*0.00*	708	1.9	15400	10700
9/12/96	33	24.0	*0.00*	698	1.9	11600	9780
12/12/96	*2.5*	12.0	*0.00*	571	1.4	9320	6970
mean[1]	42.7	12.1	0.00	623	3.2	13962	8939
stdev[2]	17.3	6.7	0.00	75	3.9	4055	1308
count[3]	10	10	9	10	10	10	10
MRL[4]	5	0.2	0.01	5	0.2	20	5
MCL[5]	none	250	none	500	none	none	none

Notes

Abbreviations: COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids;
T&L = Tannin and Lignin; Total Fe, Total Mn = Total (unfiltered) Iron and Manganese.

[1] mean = arithmetic mean of the sample set.

[2] stdev = standard deviation of the sample set.

[3] count = number of samples used to perform statistical calculations.

[4] MRL = Method Reporting Limit.

[5] MCL = Maximum Contaminant Level for drinking water in Washington State.

[6] Questionable result. Phenolics also found in some of the field blanks.

Italicized results originally reported as less-than the MRL;
- less-than values replaced per the appropriate "ND action/adjustment" protocol.

▨ = Above Washington State maximum contaminant level (WAC 246-290-310).

Table 5B. Seep B Analytical Results (ND-adjusted data)

Date	------------------ mg/L ------------------					— ug/L —	
	COD	**Cl**	**Phenol**	**TDS**	**T&L**	**Total Fe**	**Total Mn**
5/3/94	Dry	Dry	Dry	Dry	Dry	Dry	Dry
6/21/94	Dry	Dry	Dry	Dry	Dry	Dry	Dry
9/7/94	Dry	Dry	Dry	Dry	Dry	Dry	Dry
12/5/94	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged
3/9/95	28	11.0	0.12[6]	480	1.3	8790	7030
5/9/95	49	9.8	*0.00*	634	2.4	8250	9460
9/6/95	69	6.2	0.06	701	2.4	19300	10400
12/5/95	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged	Submerged
3/7/96	61	10.6	*0.00*	687	2.2	13200	9850
5/7/96	68	12.0	*0.00*	723	2.4	13900	10600
9/12/96	56	20.0	*0.00*	768	3.3	15400	12100
12/12/96	48	12.0	*0.00*	666	1.8	14500	8700
mean[1]	54.1	11.7	0.01	666	2.3	13334	9734
stdev[2]	14.2	4.2	0.02	92	0.6	3831	1595
count[3]	7	7	6	7	7	7	7
MRL[4]	5	0.2	0.01	5	0.2	20	5
MCL[5]	none	250	none	500	none	none	none

Notes

Abbreviations: COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; T&L = Tannin and Lignin; Total Fe, Total Mn = Total (unfiltered) Iron and Manganese.

[1] mean = arithmetic mean of the sample set.

[2] stdev = standard deviation of the sample set.

[3] count = number of samples used to perform statistical calculations.

[4] MRL = Method Reporting Limit.

[5] MCL = Maximum Contaminant Level for drinking water in Washington State.

[6] Questionable result. Phenolics also found in some of the field blanks; laboratory contamination suspected.

Italicized results originally reported as less-than the MRL;

- less-than values replaced per the appropriate "ND action/adjustment" protocol.

▨ = Above Washington State maximum contaminant level (WAC 246-290-310).

Table 6. Lagoon Sampling Analytical Results (ND-adjusted data)

	---------------------------- mg/L ----------------------------									--- ug/L ---		S.U.
Date	**COD**	**Cl**	**Phenol**	**TDS**	**TSS**	**T&L**	**TRPH**	**Oil & Grease**	**Formal-dehyde**	**Total Fe**	**Total Mn**	**pH[1]**
6/22/94	2840	750	0.62	3520	282	82	0.25	143	*0.0*	2830	501	8.26
9/7/94	2870	540	0.90	2750	154	71	0.25	91	*0.0*	1550	675	8.27
12/5/94	2000	550	0.51	3090	168	62	2.2	160	*0.0*	3660	1230	8.28
3/9/95	1730	310	0.31	2140	132	59	4.4	60	*0.0*	3930	541	8.30
6/9/95	1720	230	0.17	1990	64	35	15.0	72	0.5	1200	460	8.27
9/7/95	1800	230	0.23	2050	246	35	0.9	62	*0.0*	809	557	8.31
12/5/95	1230	190	0.20	1490	109	10.4	0.4	80	0.3	2440	464	8.62
3/6/96	2060	230	0.27	2430	188	49	6.3	86	*0.0*	1600	571	8.52
6/7/96	1680	200	0.19	1560	490	40	6.0	32	0.3	5430	997	8.49
9/12/96	735	72	0.11	859	64	27	1.3	57	*0.0*	908	229	8.50
12/11/96	931	130	0.16	1080	111	31	7.8	70	1.0	1930	293	9.24
mean[2]	1781	312	0.33	2087	183	45.6	4.1	83.0	0.2	2390	593	8.46
stdev[3]	676	209	0.24	824	123	21.2	4.5	37.6	0.3	1452	291	0.29
count[4]	11	11	11	11	11	11	11	11	11	11	11	11
MRL[5]	5	0.2	0.01	5	5	0.2	0.5	5	0.2 [7]	20	5	NA
MCL[6]	none	250	none	500	none	none	none	none	none	none	none	none

Notes

Abbreviations: COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; TSS = Total Suspended Solids; T&L = Tannin and Lignin: TRPH = Total Recoverable Petroleum Hydrocarbons; Total Fe, Total Mn = Total (unfiltered) Iron and Manganese.

[1] pH always measured after the recommended hold time of 24 hours.

[2] mean = arithmetic mean of the sample set.

[3] stdev = standard deviation of the sample set.

[4] count = number of samples used to perform statistical calculations

[5] MRL = method reporting limit.

[6] MCL = Maximum Contaminant Level for drinking water in Washington State.

[7] From June 1995 to December 1996 the Formaldehyde MRL was 0.2 mg/L; earlier MRLs as shown.

Italicized results originally reported as less-than the MRL; less-than values replaced as per the appropriate "ND action/adjustment" protocol.

Table 7. Analytical Data Summary (ND-adjusted data) -- All Wells, Seeps and Lagoon

Analyte[1]	LAGOON AREA MEAN VALUES[2]									LOG DECK AREA MEAN VALUES[2]					
	P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	average mean	stdev[3] of the means	P-4	P-4D	P-5	P-7	average mean	stdev[3] of the means
COD (mg/L)	16	33	7.8	10	54	15	2.7	20	18	4.0	2.0	10	13	7.2	5.2
Cl (mg/L)	80	125	33	142	334	159	39	130	102	19	12	1.0	7.9	10	7.5
Phenol (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS (mg/L)	731	790	481	831	1460	867	426	798	339	481	443	267	391	396	93
T&L (mg/L)	0.23	0.94	0.00	0.04	0.60	0.16	0.04	0.29	0.35	0.07	0.07	0.05	0.17	0.09	0.06
Diss. Fe (ug/L)	39	41	30	51	46	44	38	41	6.9	89	65	33	58	61	23
Diss. Mn (ug/L)	22	2021	42	0.6	160	0.0	0.0	321	752	0.0	0.0	22	28	13	15

Analyte[1]	MEAN VALUES[2]		
	Seep A	Seep B	Lagoon
COD (mg/L)	43	54	1781
Cl (mg/L)	12	12	312
Phenol (mg/L)	0.00	0.01	0.33
TDS (mg/L)	623	666	2087
T&L (mg/L)	3.2	2.3	46
Total Fe (ug/L)	13962	13334	2390
Total Mn (ug/L)	8939	9734	593
TSS (mg/L)	-	-	183
TRPH (mg/L)	-	-	4.1
O&G (mg/L)	-	-	83
Form. (mg/L)	-	-	0.19
pH	-	-	8.5

Notes

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[1] COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; T&L = Tannin & Lignin; Diss. Fe, Diss. Mn = Dissolved (filtered) Iron and Manganese; Total Fe, Total Mn = Total (unfiltered) Iron and Manganese; TSS = Total Suspended Solids; TRPH = Total Recoverable Petroleum Hydrocarbons; O&G = Oil & Grease; Form. = Formaldehyde.

[2] Mean Values = arithmetic mean of each sample set, corrected using the appropriate "ND action/adjustment."

[3] stdev = standard deviation (of the mean values).

Table 8. Analytical Data Correlations with Lake Elevation

Well	COD			Cl			Phenol			TDS			T&L			Fe			Mn		
	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?	Corr. Coef.	P-value	Lake Elev. Corr.?
P-1	-0.1607	0.4328	no	-0.2957	0.1425	no	-0.0814	0.6988	no	-0.4191	0.0331	yes (-)	-0.1979	0.3326	no	0.0560	0.7858	no	-0.1989	0.3301	no
P-1D	0.6593	0.0001	yes (+)	0.7391	0.0000	yes (+)	-0.0578	0.7660	no	0.7950	0.0000	yes (+)	0.3624	0.0451	yes (+)	0.3048	0.1015	no	0.3961	0.0274	yes (+)
P-2	0.0910	0.8302	no	0.3079	0.4581	no	-0.0006	0.9988	no	0.0391	0.9268	no			no	0.0277	0.9530	no	0.4703	0.2396	no
P-2D	-0.3405	0.1668	no	-0.5071	0.0317	yes (-)	-0.1755	0.4860	no	-0.1545	0.5405	no	-0.2849	0.2518	no	-0.0140	0.9605	no	0.0764	0.7867	no
P-3	-0.0598	0.7765	no	-0.0546	0.7955	no	-0.1141	0.6042	no	-0.1049	0.6177	no	0.0308	0.8838	no	-0.1579	0.4510	no	-0.2070	0.3209	no
P-3D	-0.7149	0.0001	yes (-)	-0.3552	0.0885	no			no	-0.4787	0.0180	yes (-)	-0.6041	0.0018	yes (-)	0.0424	0.8439	no			no
P-4	0.1326	0.5666	no	-0.1622	0.4823	no	0.1026	0.6582	no	-0.2268	0.3228	no	-0.3743	0.0946	no	0.1731	0.4655	no			no
P-4D	-0.0667	0.7213	no	-0.3042	0.0961	no			no	0.3217	0.0776	no	0.0353	0.8503	no	-0.1297	0.4945	no			no
P-5	0.0754	0.8066	no	-0.1706	0.5774	no	0.0915	0.7774	no	0.2710	0.3704	no	-0.3981	0.1779	no	-0.5255	0.0793	no	0.0782	0.7996	no
P-7	-0.0179	0.9584	no	0.1700	0.6172	no	0.1247	0.7149	no	0.2537	0.4515	no	-0.0448	0.8959	no	0.3187	0.3694	no	0.5008	0.1167	no
P-8	-0.4682	0.1066	no	0.4208	0.1522	no			no	0.5374	0.0582	no	-0.3299	0.2710	no	0.0512	0.8812	no			no

Notes

COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; T&L = Tannin and Lignin; Fe, Mn = Dissolved (filtered) Iron and Manganese.

Correlation Coefficients and P-Values calculated using *Statistix Analytical Software*, Windows Version 1.0, Copyright 1996.

- data set determined to be correlated with lake elevation if P-Value < 0.05 and Corr. Coef. > 0.1 or <-0.1
- yes (+) = positive lake-elevation correlation; yes (-) = negative lake-elevation correlation; no = no statistically-significant lake-elevation correlation.

Blank cells indicate that correlation evaluation could not be performed due to insufficient number of non-zero data points.

Table 9A. Temporal Trend Analysis Summary -- Groundwater Data - Linear Regressions

Analytical Parameter	Regression Analyses	LAGOON AREA							LOG DECK AREA			
		P-1	P-1D	P-2	P-2D	P-3	P-3D	P-8	P-4	P-4D	P-5	P-7
COD	**P-Value**	0.1212	0.2930	0.0519	0.4154	0.0000	0.9058	0.1434	0.6189	0.7717	0.0032	0.1499
	R^2	-	-	0.4938	-	0.6187	-	-	-	-	0.5620	-
	Regr. Coef.	-	-	-0.0148	-	-0.0557	-	-	-	-	-0.0283	-
Cl	**P-Value**	0.1870	0.9771	0.8688	0.4000	0.0000	0.6883	0.0083	0.0000	0.0093	0.5435	0.4254
	R^2	-	-	-	-	0.6245	-	0.4840	0.5937	0.2111	-	-
	Regr. Coef.	-	-	-	-	-0.4089	-	0.0394	-0.0098	0.0029	-	-
Phenol	**P-Value**	0.3530	0.5460	0.1223	0.5077	0.1299	CNBD	CNBD	0.0132	CNBD	0.5111	0.6136
	R^2	-	-	-	-	-	-	-	0.2825	-	-	-
	Regr. Coef.	-	-	-	-	-	-	-	-5.95E-06	-	-	-
TDS	**P-Value**	0.1342	0.6226	0.5872	0.1201	0.0000	0.0829	0.0773	0.0006	0.0443	0.7625	0.5578
	R^2	-	-	-	-	0.6753	-	-	0.4714	0.1322	-	-
	Regr. Coef.	-	-	-	-	-1.1769	-	-	0.0603	0.0285	-	-
T&L	**P-Value**	0.0262	0.0478	CNBD	0.4452	0.0003	0.8152	0.8028	0.9054	0.4505	0.1038	0.5142
	R^2	0.1896	0.1283	-	-	0.4427	-	-	-	-	-	-
	Regr. Coef.	-0.0003	-0.0010	-	-	-0.0005	-	-	-	-	-	-
Fe	**P-Value**	0.8362	0.9603	0.3020	0.1343	0.0001	0.8161	0.0566	0.1594	0.0032	0.3402	0.3469
	R^2	-	-	-	-	0.4948	-	-	-	0.2708	-	-
	Regr. Coef.	-	-	-	-	-0.0253	-	-	-	0.0892	-	-
Mn	**P-Value**	0.0133	0.0435	0.0669	0.8390	0.0000	CNBD	CNBD	CNBD	CNBD	0.0060	0.0048
	R^2	0.2296	0.1332	-	-	0.6175	-	-	-	-	0.5120	0.6053
	Regr. Coef.	-0.0886	-2.5021	-	-	-0.1604	-	-	-	-	-0.0279	-0.0510

Notes

COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; T&L = Tannin & Lignin; Fe, Mn = Dissolved (filtered) Iron and Manganese.

Unweighted least-squares linear regressions performed using *Statistix Analytical Software*, Windows Version 1.0, Copyright 1996.

P-Value: a statistically significant upward or downward temporal trend in a given data set indicated by a P-value of < 0.05.

- regression analyses results reported only for those data sets with P-values < 0.05.

R^2 is the square of the correlation coefficient which measures the overall deviation from the "best fit" line of the regression.

- R^2 values range from 0 to 1, with 1 being an exact fit.

Regr. Coef. is the coefficient of the linear regression which measures the "strength" of the temporal trend, i.e., the slope of the "best fit" line.

- negative values indicate a decreasing trend through time; positive values indicate an increasing trend through time.

CNBD = Could Not Be Determined due to insufficient number of non-zero data points.

Table 9B. Temporal Trend Analysis Summary -- Seep and Lagoon Data - Linear Regressions

Analytical Parameter	Regression Analyses	Seep A	Seep B	Lagoon
COD	**P-Value**	0.0414	0.4077	0.0012
	R^2	0.4241	-	0.7077
	Regr. Coef.	-0.0330	-	-1.8834
Cl	**P-Value**	0.0043	0.1829	0.0002
	R^2	0.6604	-	0.7952
	Regr. Coef.	0.0159	-	-0.6186
Phenol	**P-Value**	CNBD	0.4032	0.0031
	R^2	-	-	0.6392
	Regr. Coef.	-	-	-0.0006
TDS	**P-Value**	0.2903	0.0860	0.0003
	R^2	-	-	0.7881
	Regr. Coef.	-	-	-2.4218
T&L	**P-Value**	0.5475	0.3825	0.0059
	R^2	-	-	0.5884
	Regr. Coef.	-	-	-0.0538
Total Fe	**P-Value**	0.7687	0.2463	0.7491
	R^2	-	-	-
	Regr. Coef.	-	-	-
Total Mn	**P-Value**	0.4366	0.2615	0.2677
	R^2	-	-	-
	Regr. Coef.	-	-	-
TSS (Lagoon only)	**P-Value**	-	-	0.9502
	R^2	-	-	-
	Regr. Coef.	-	-	-
TRPH (Lagoon only)	**P-Value**	-	-	0.4025
	R^2	-	-	-
	Regr. Coef.	-	-	-
Oil & Grease (Lagoon only)	**P-Value**	-	-	0.0274
	R^2	-	-	0.4343
	Regr. Coef.	-	-	-0.0821
Formaldehyde (Lagoon only)	**P-Value**	-	-	0.0880
	R^2	-	-	-
	Regr. Coef.	-	-	-
pH (Lagoon only)	**P-Value**	-	-	0.0068
	R^2	-	-	0.5760
	Regr. Coef.	-	-	0.0007

Notes

COD = Chemical Oxygen Demand; Cl = Chloride; Phenol = Total Phenolics; TDS = Total Dissolved Solids; TSS = Total Suspended Solids; T&L = Tannin & Lignin: TRPH = Total Recoverable Petroleum Hydrocarbons; Total Fe, Total Mn = Total (unfiltered) Iron and Manganese.

Unweighted least-squares linear regressions performed using *Statistix Analytical Software,* Windows Version 1.0, Copyright 1996.

P-Value: a statistically significant upward or downward temporal trend in a given data set indicated by a P-value of < 0.05.

- regression analyses results reported only for those data sets with P-values < 0.05.

R^2 is the square of the correlation coefficient which measures the overall deviation from the "best fit" line of the regression.

- R^2 values range from 0 to 1, with 1 being an exact fit.

Regr. Coef. is the coefficient of the linear regression which measures the "strength" of the temporal trend, i.e., the slope of the "best fit" line.

- negative values indicate a decreasing trend through time; positive values indicate an increasing trend through time.

CNBD = Could Not Be Determined due to insufficient number of non-zero data points.

Figures

scale 1:700,000

contour interval = 500 feet (152 meters)

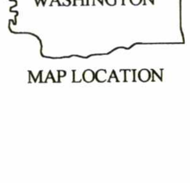


Figure 1. Site Location Topographic Map

source: USGS State of Washington Topographic Map (1982)

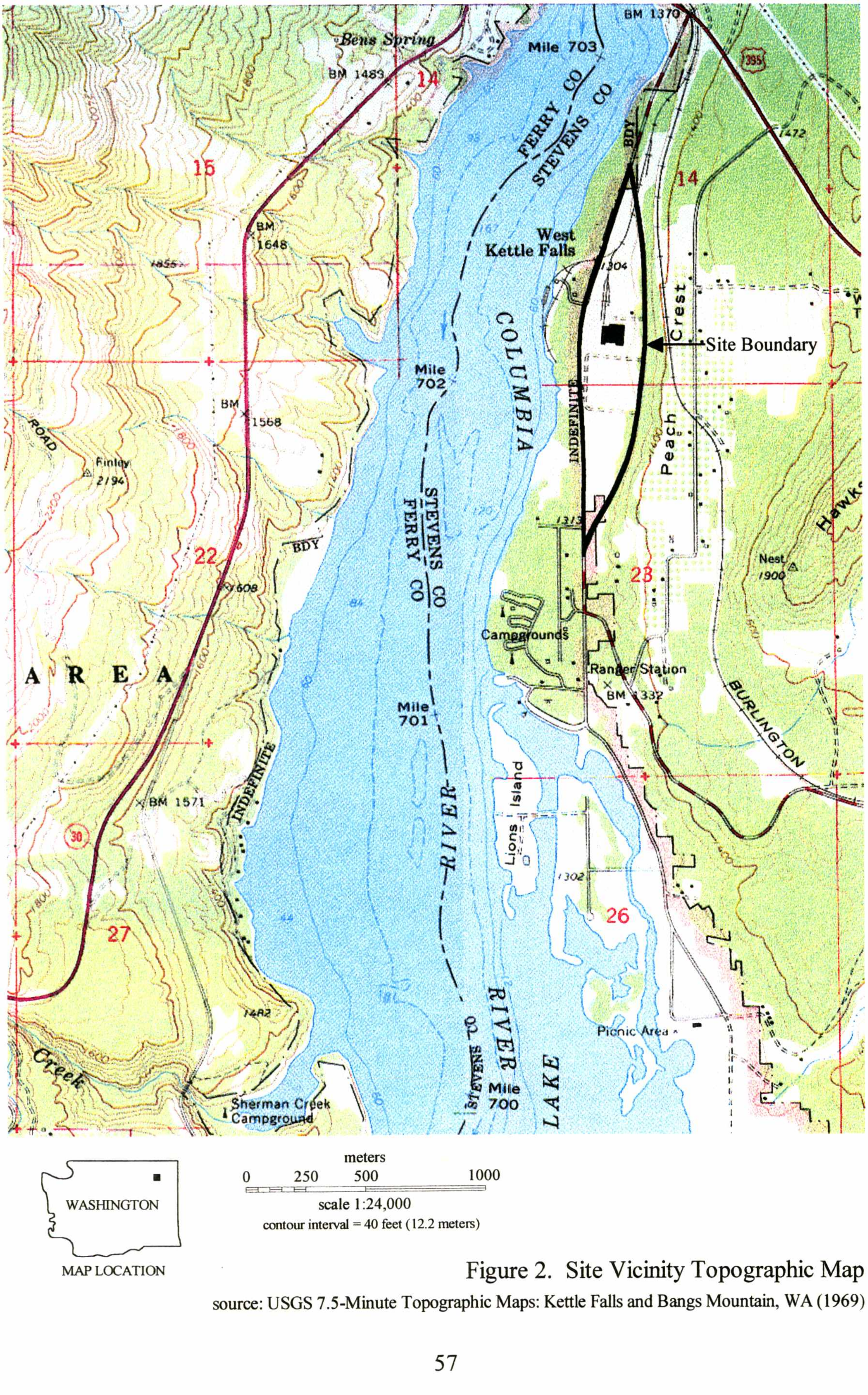


Figure 2. Site Vicinity Topographic Map

source: USGS 7.5-Minute Topographic Maps: Kettle Falls and Bangs Mountain, WA (1969)

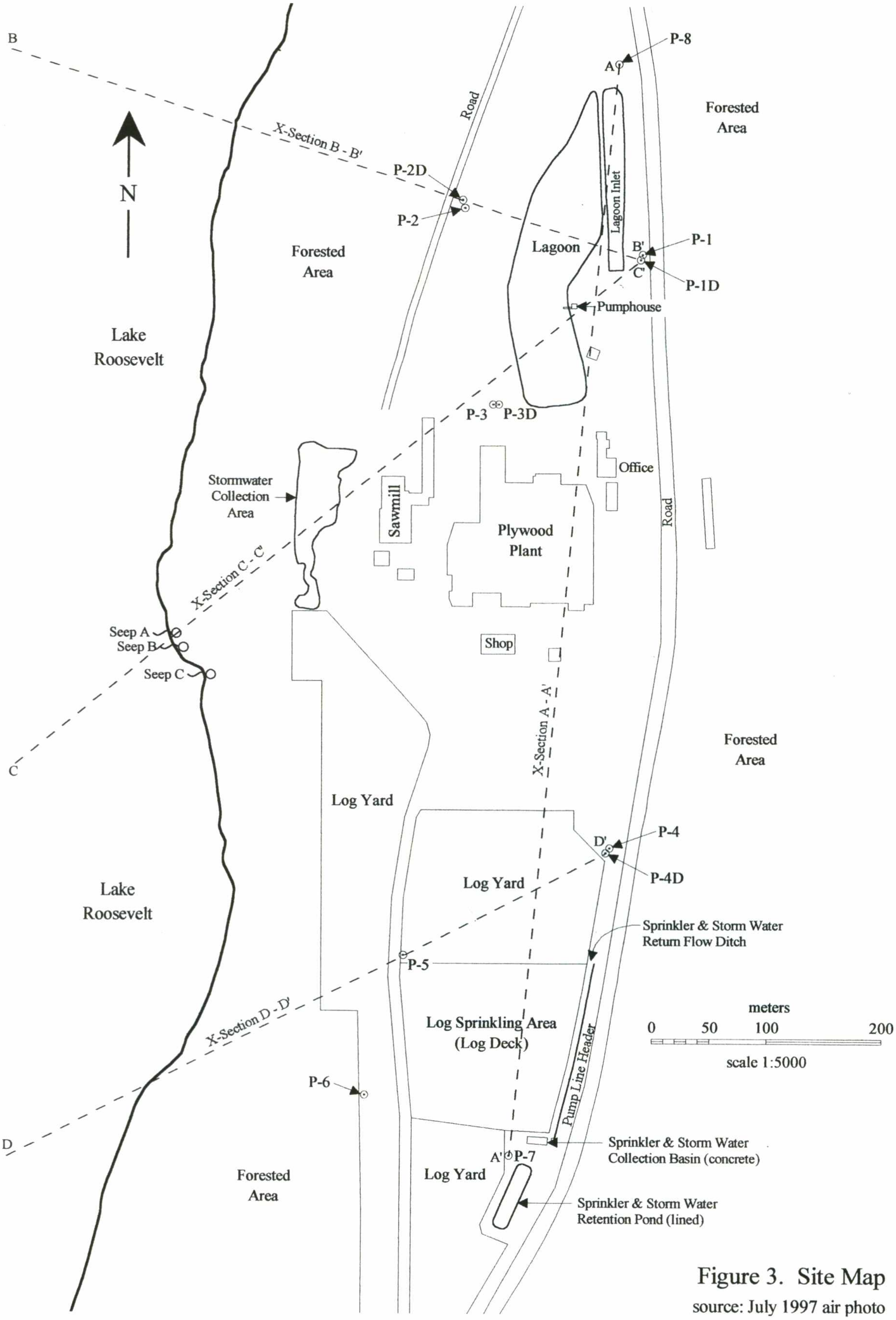
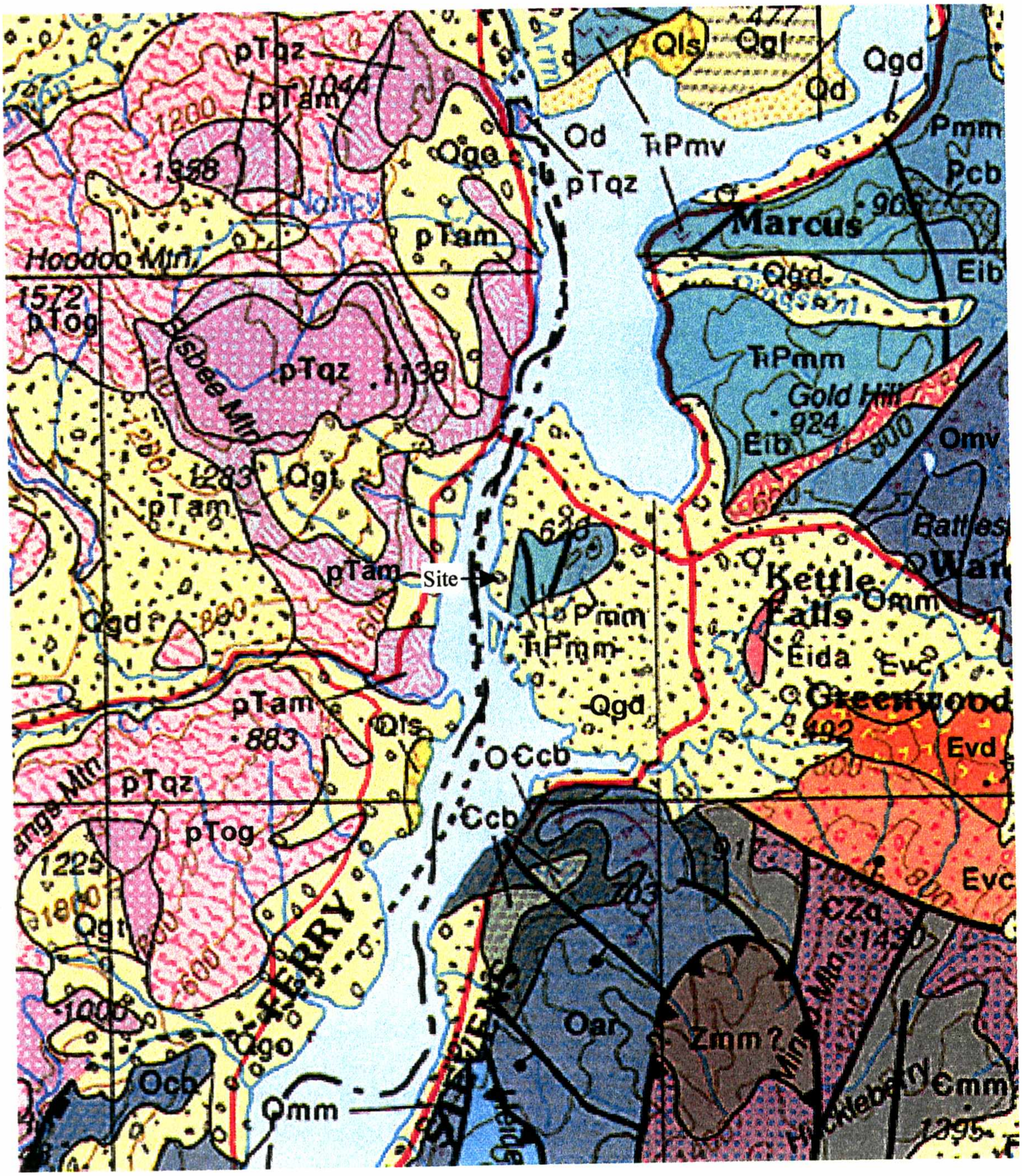


Figure 3. Site Map
source: July 1997 air photo



Geologic Units in Site Vicinity and other Important Units

Qls = Quaternary mass-wasting deposits
Qd = Quaternary dune sand
Qgt = Quaternary glacial till
Qgo = Quaternary glacial outwash
Qgl = Quaternary glaciolacustrine deposits
Qgd = Quaternary glacial drift

Eida = Eocene intrusive dacite and andesite
Eib = Eocene intrusive basic rocks
Evd = Eocene dacite & andesite flows
Evc = Eocene volcaniclastic rocks

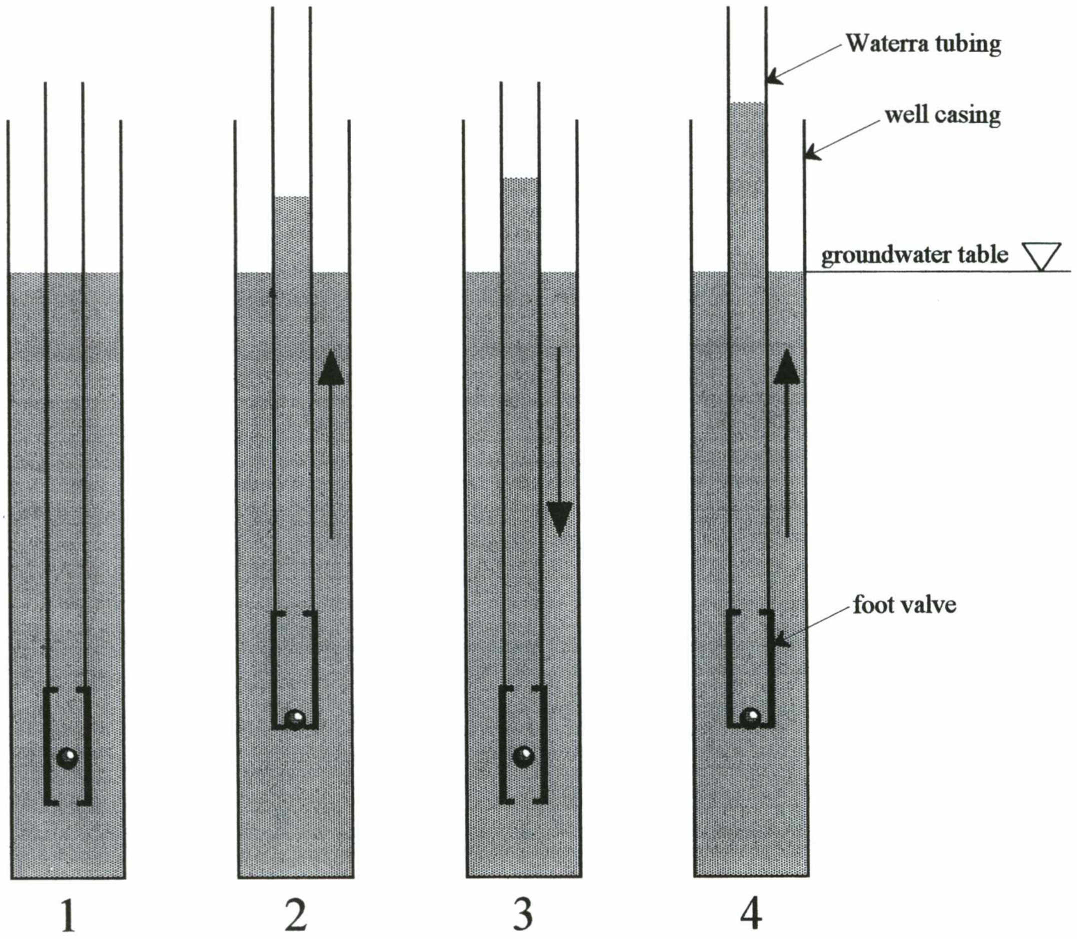
TRPmm = Triassic/Permian marine metasedimentary rocks
Pmm = Permian marine metasedimentary rocks

pTog = Pre-Tertiary orthogneiss
pTam = Pre-Tertiary amphibolite
pTqz = Pre-Tertiary quartzite

meters
0 2500 5000
scale 1:125,000

Figure 4. Geologic Map of Site Vicinity

source: Geologic Map of Washington (DNR, 1991)



1. Waterra tubing installed in well; water rises in tube to groundwater table.

2. Tubing upstroke closes the foot valve and lifts the groundwater upward.

3. Tubing downstroke opens the foot valve and forces additional water into the tubing, while the momentum from the previous upstroke continues to move the groundwater upward slightly.

4. Cycle is repeated and groundwater continues to rise in short pulses and discharges at the surface.

Figure 5. Waterra Inertial-Lift Groundwater Sampling System (Operational Schematic)

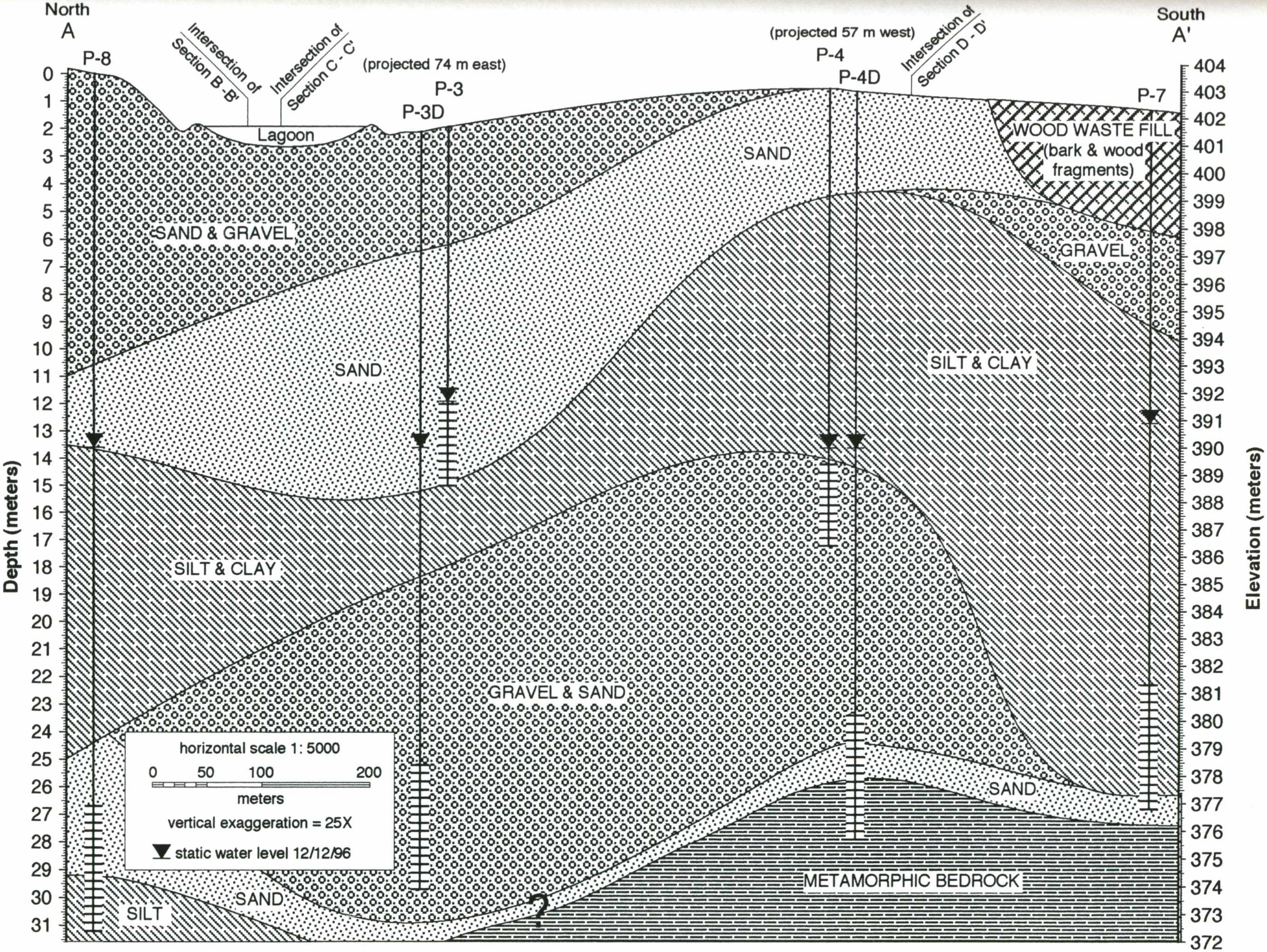
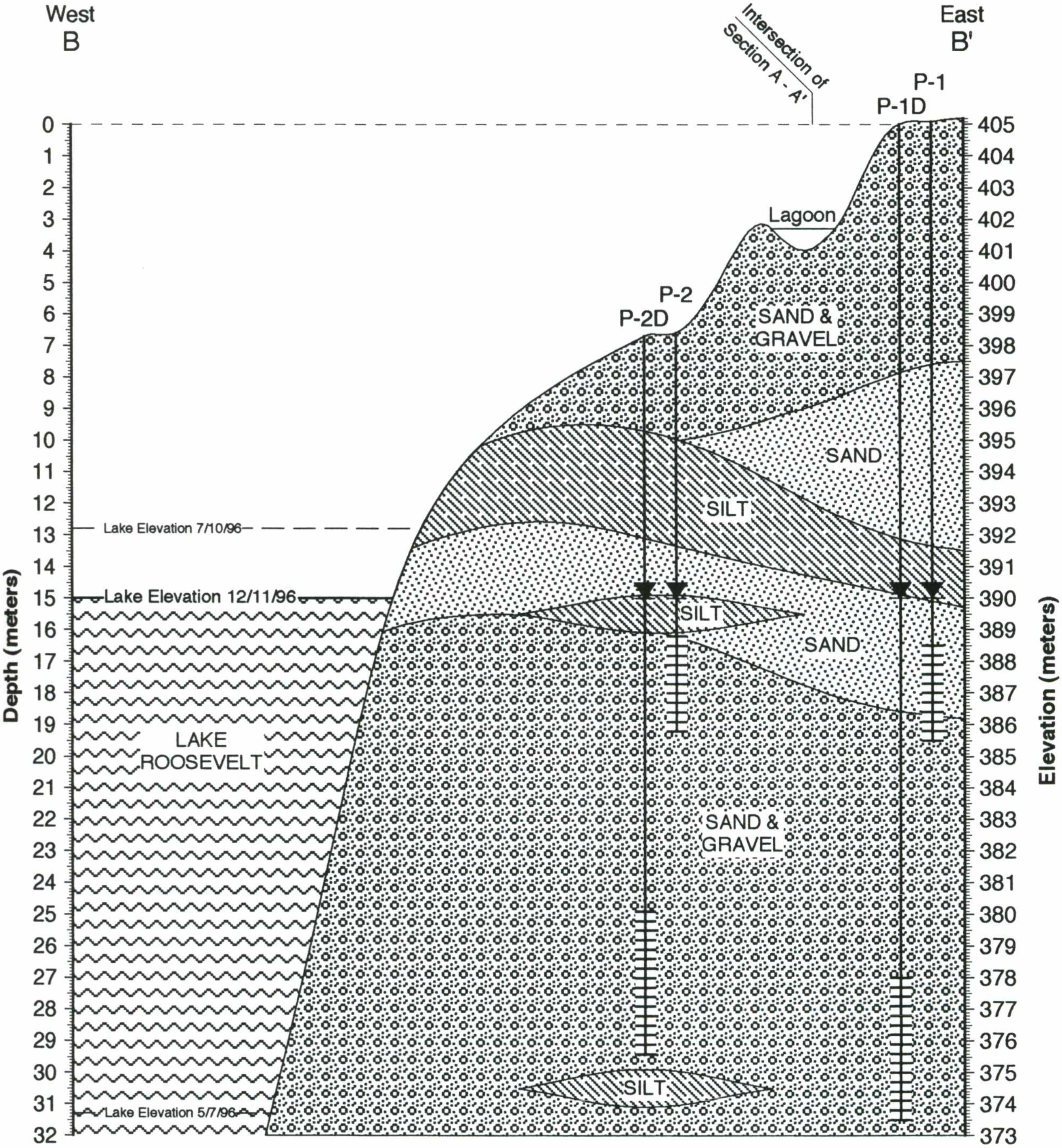


Figure 6. Stratigraphic Cross Section A - A'



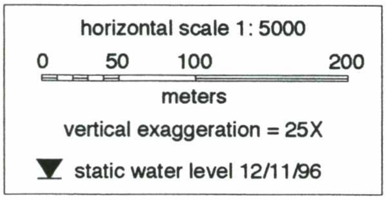


Figure 7. Stratigraphic Cross Section B - B'

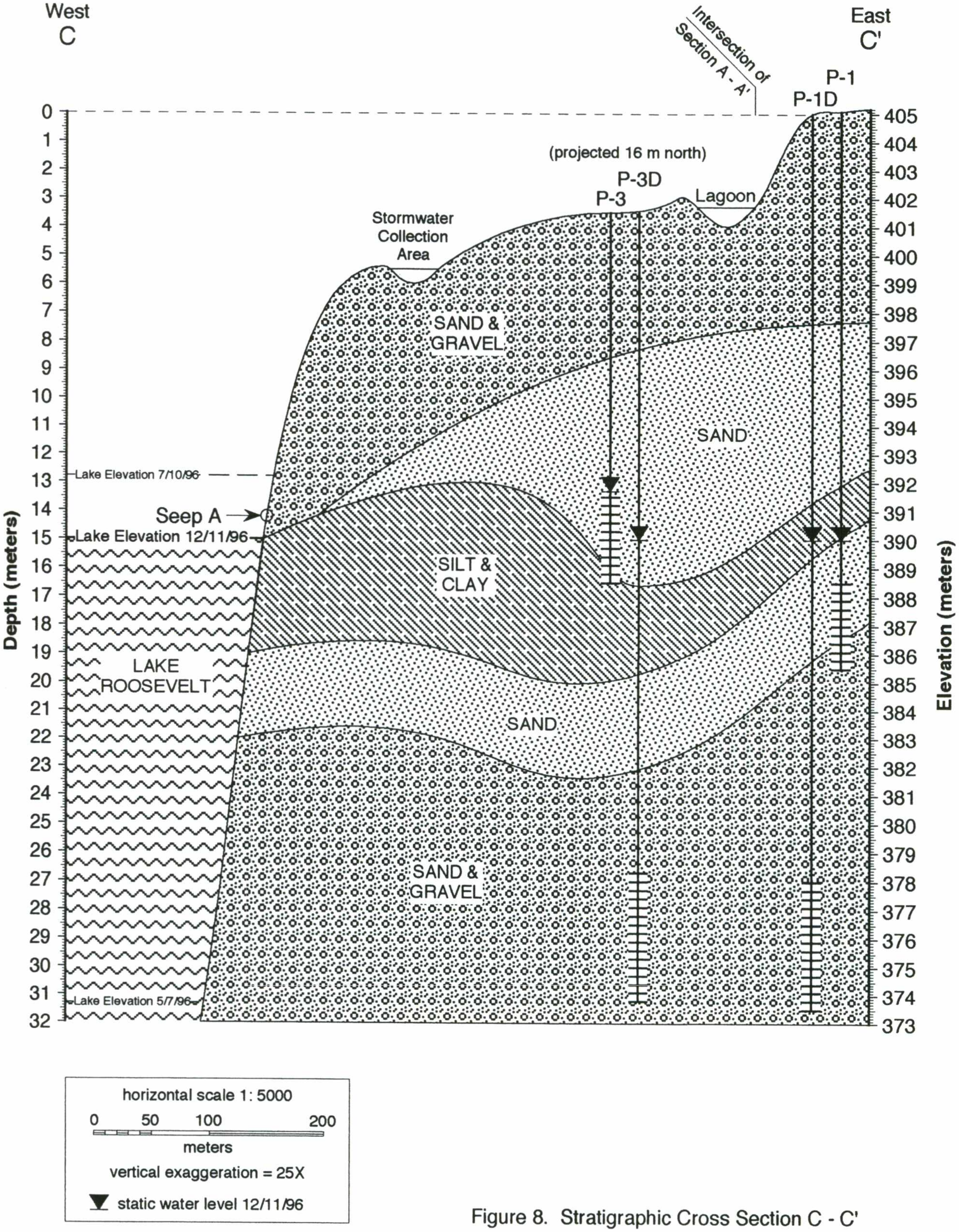


Figure 8. Stratigraphic Cross Section C - C'

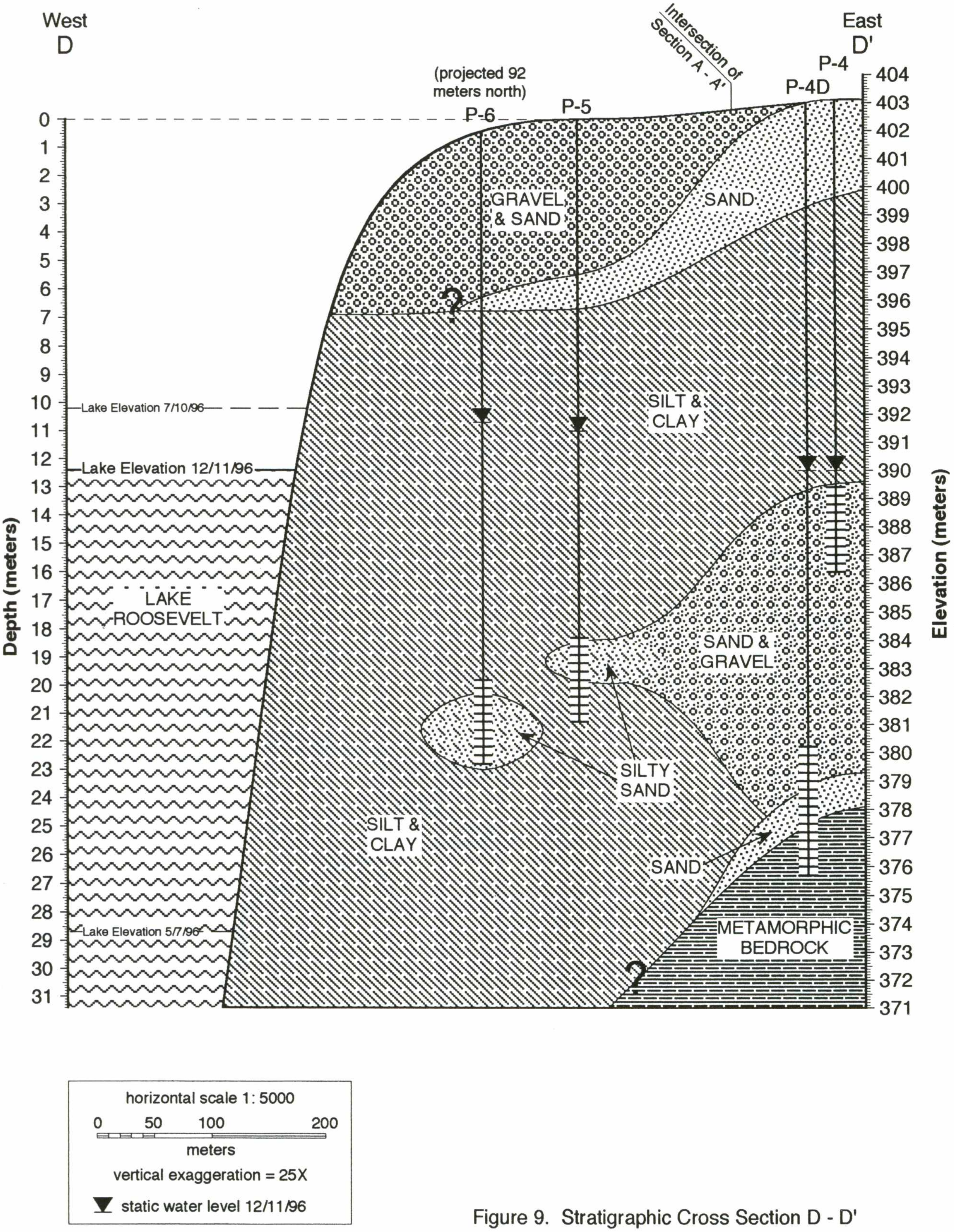
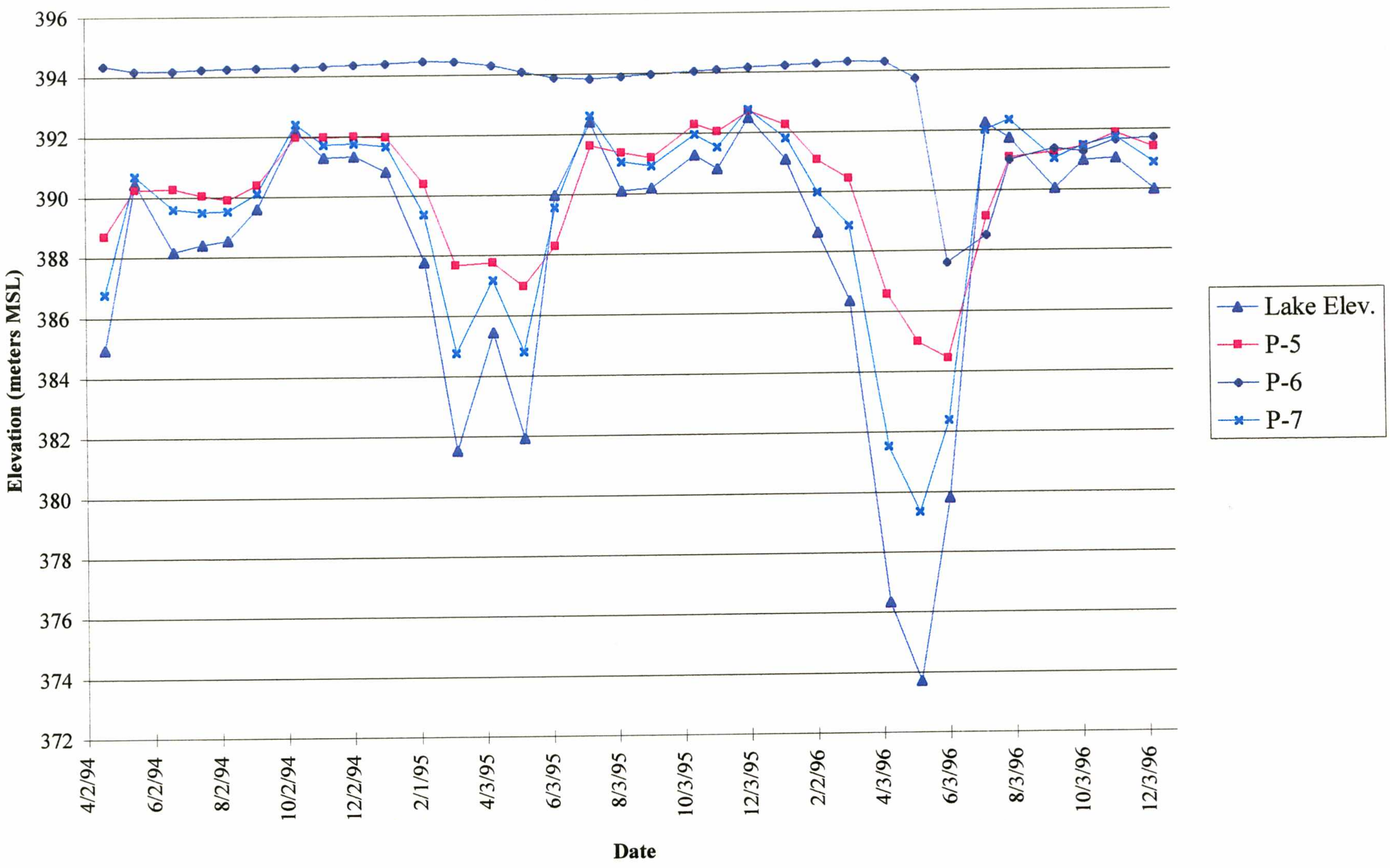


Figure 9. Stratigraphic Cross Section D - D'

Figure 10. Hydrograph of Lagoon Area Groundwater and Lake Roosevelt Elevations (including the P-4 wells)

Figure 11. Hydrograph of Log Deck Area Groundwater and Lake Roosevelt Elevations (excluding the P-4 wells)



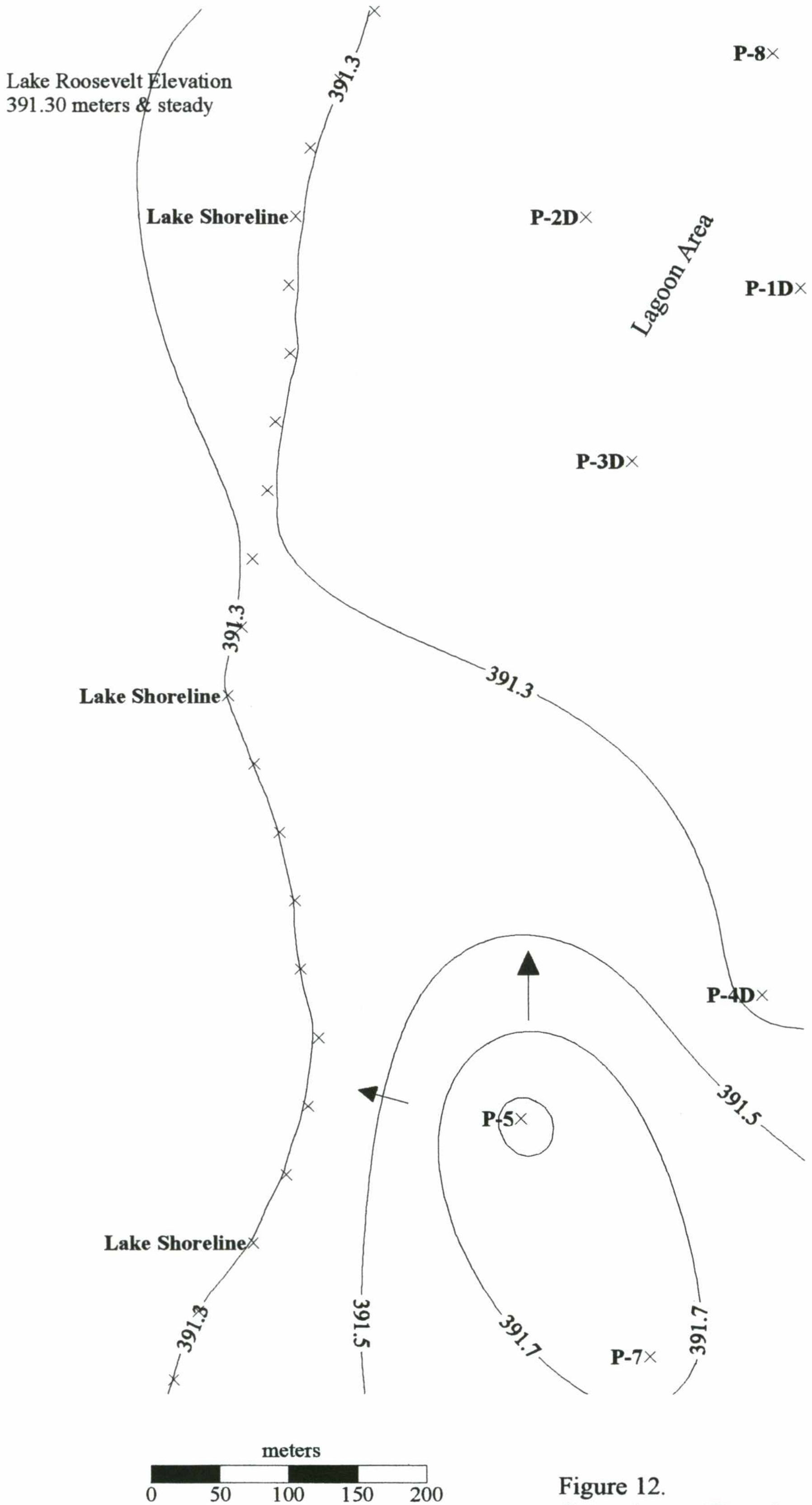


Figure 12.
Groundwater Elevation Contour Map - 12/5/94
Contour Interval = 0.2 meters

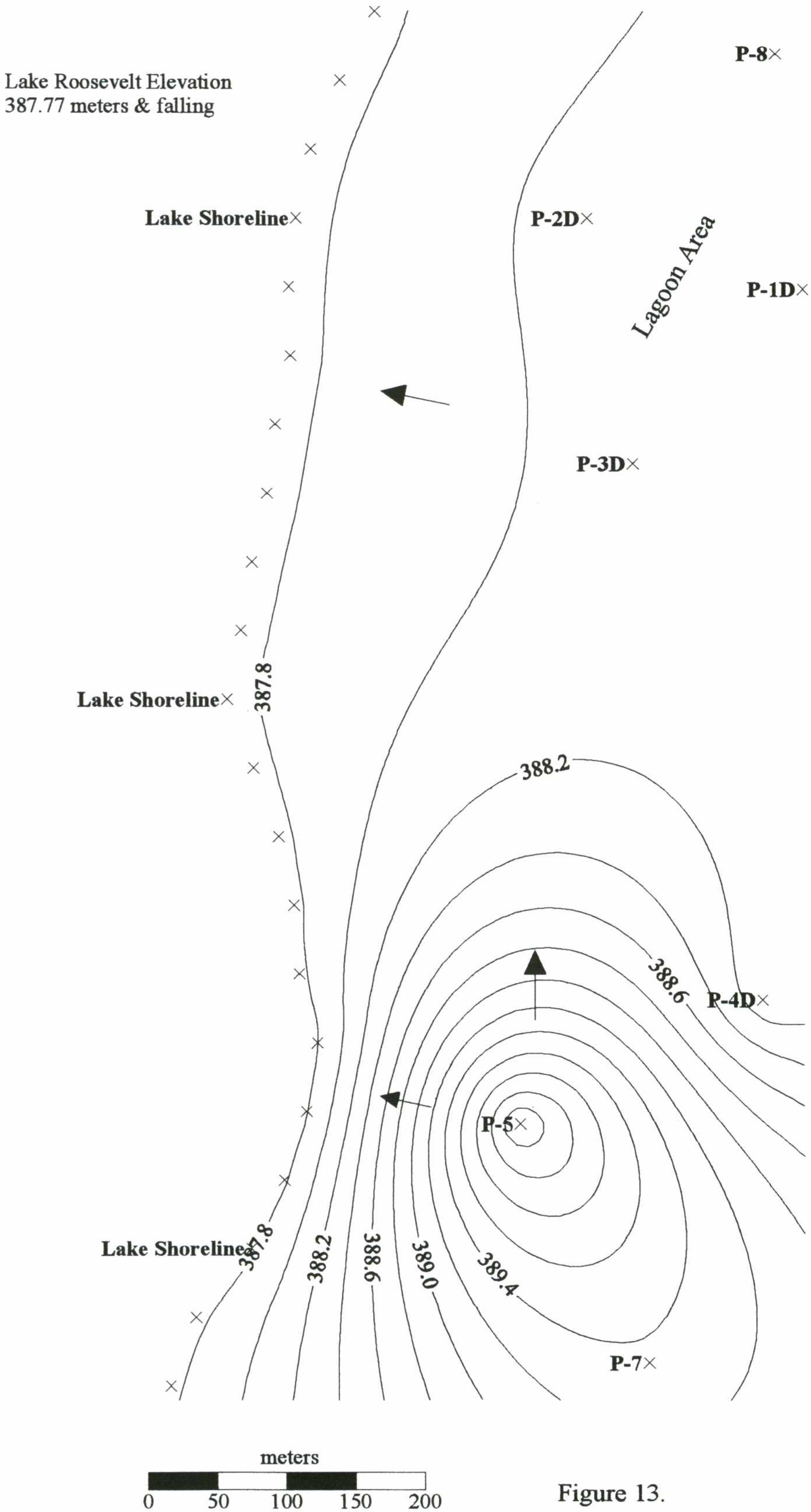


Figure 13.
Groundwater Elevation Contour Map - 2/7/95
Contour Interval = 0.2 meters

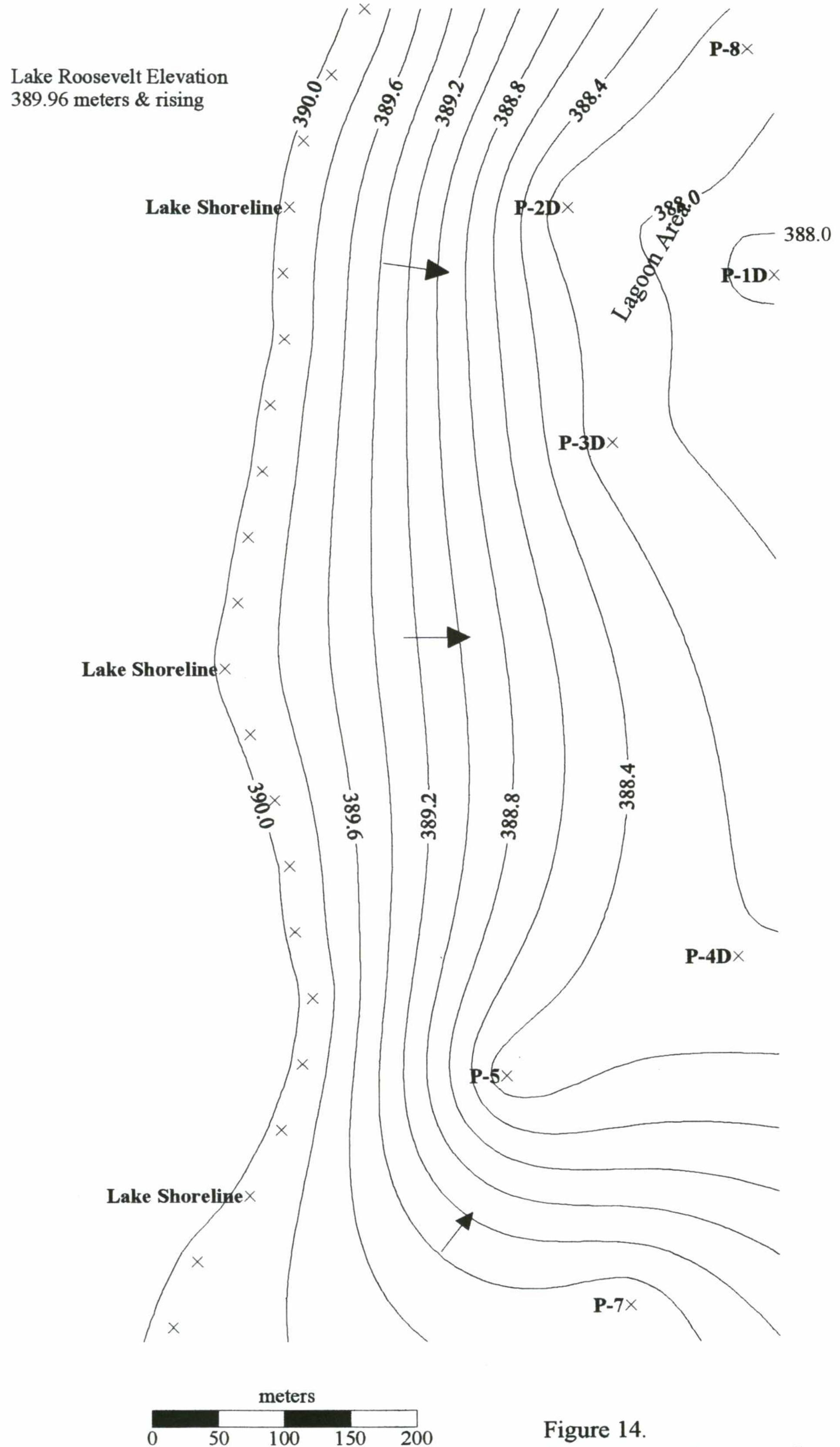


Figure 14.
Groundwater Elevation Contour Map - 6/8/95
Contour Interval = 0.2 meters

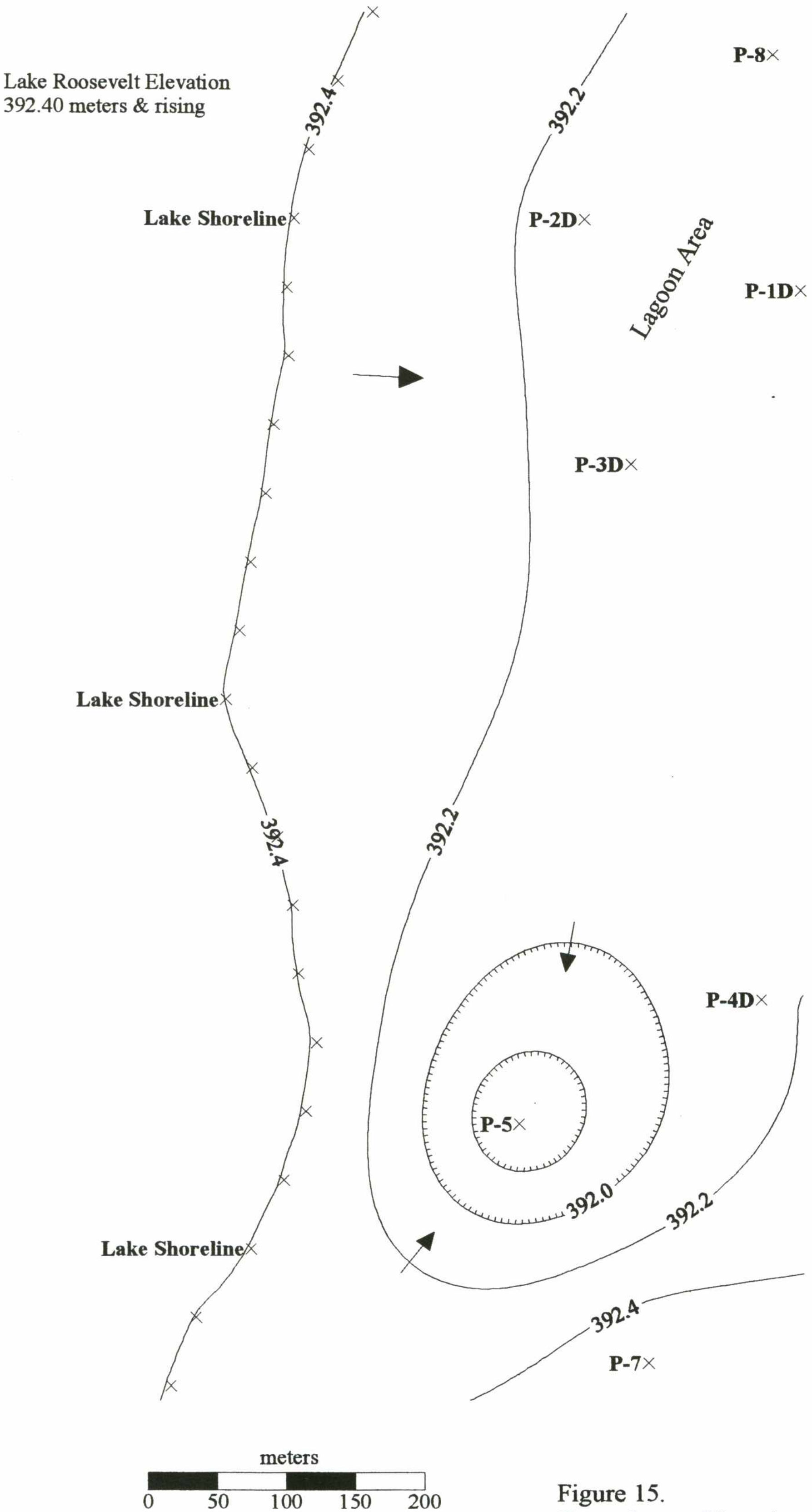
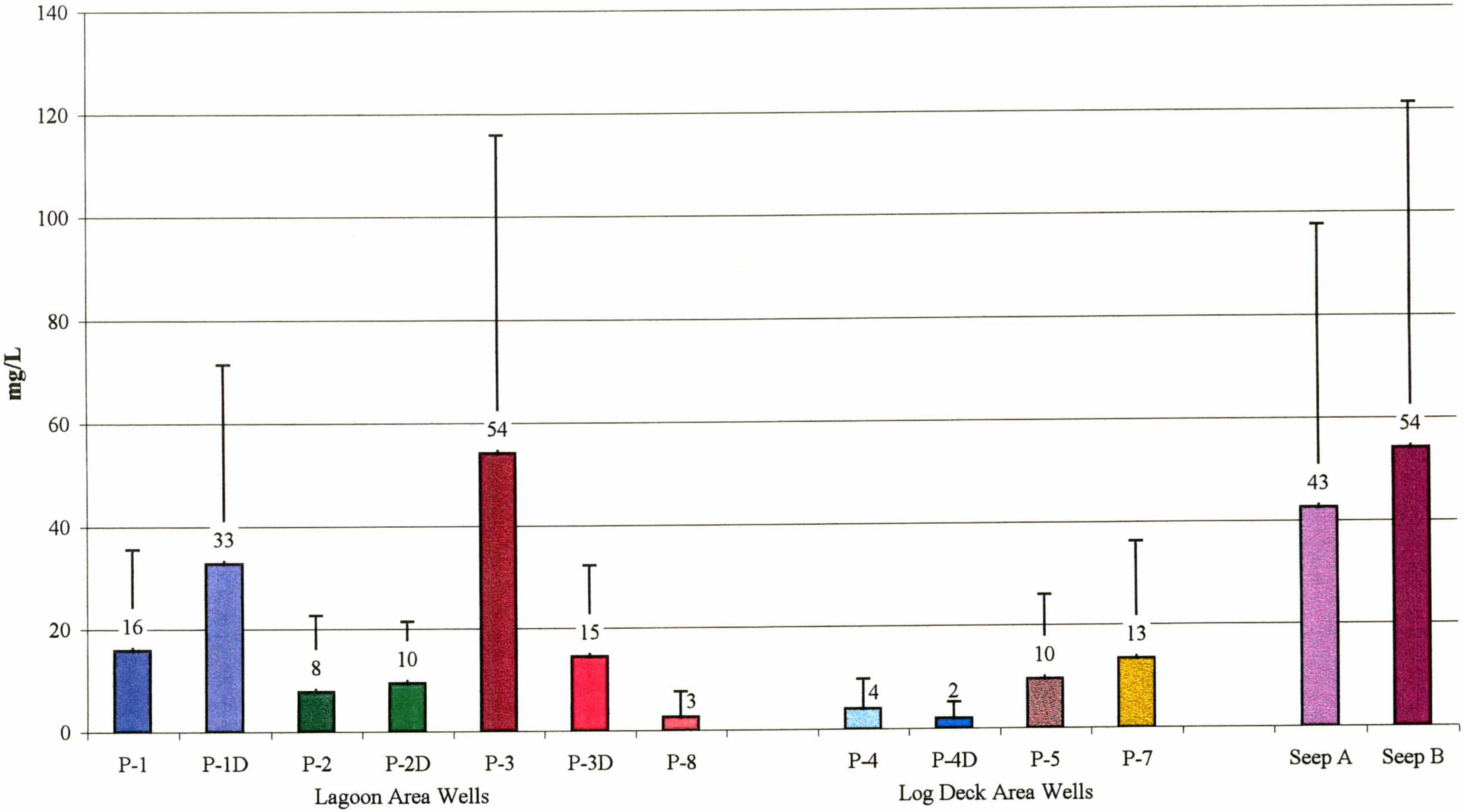


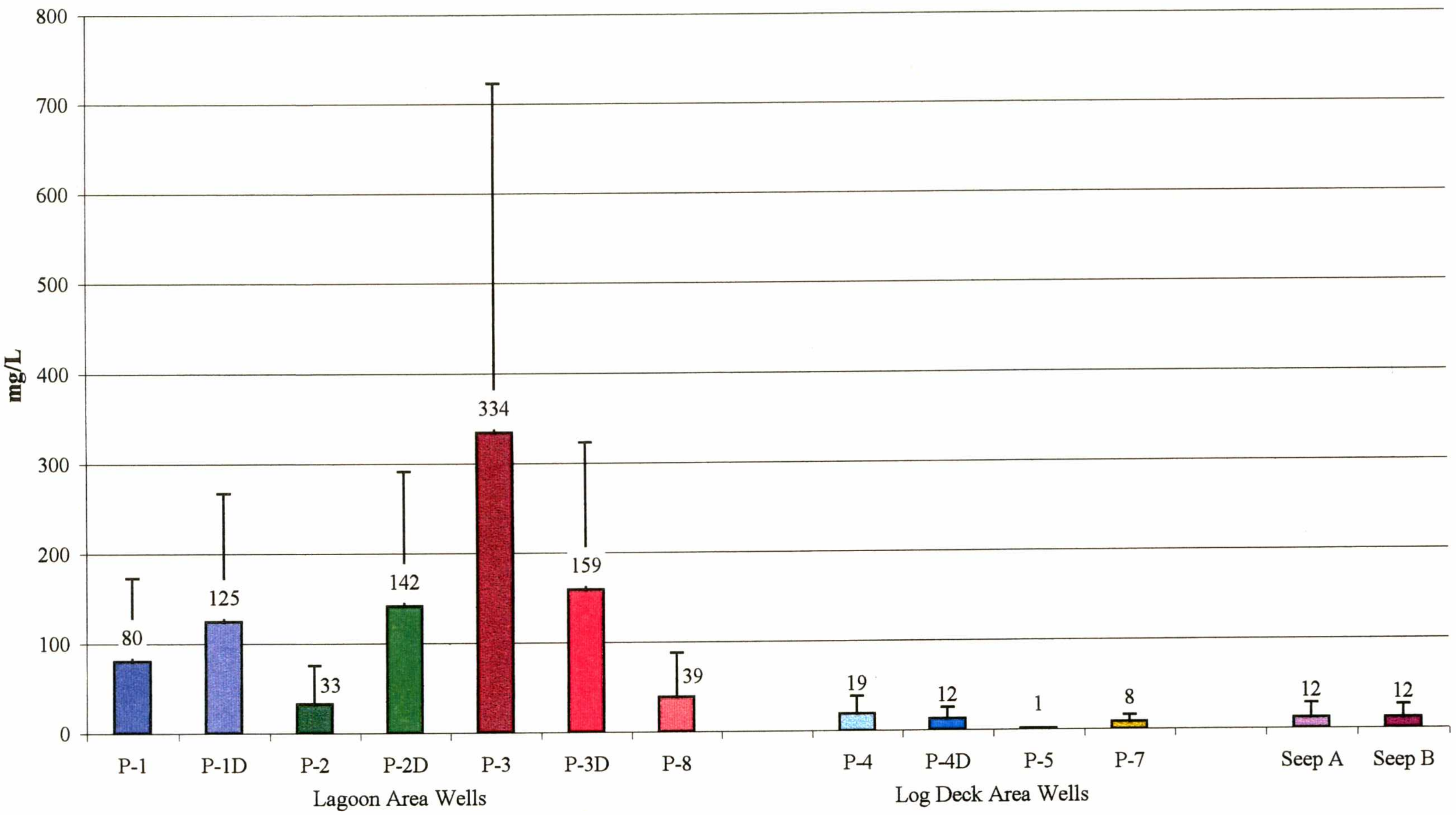
Figure 15.
Groundwater Elevation Contour Map - 7/11/95
Contour Interval = 0.2 meters

Figure 16. Mean Chemical Oxygen Demand (COD) Concentrations (mg/L)



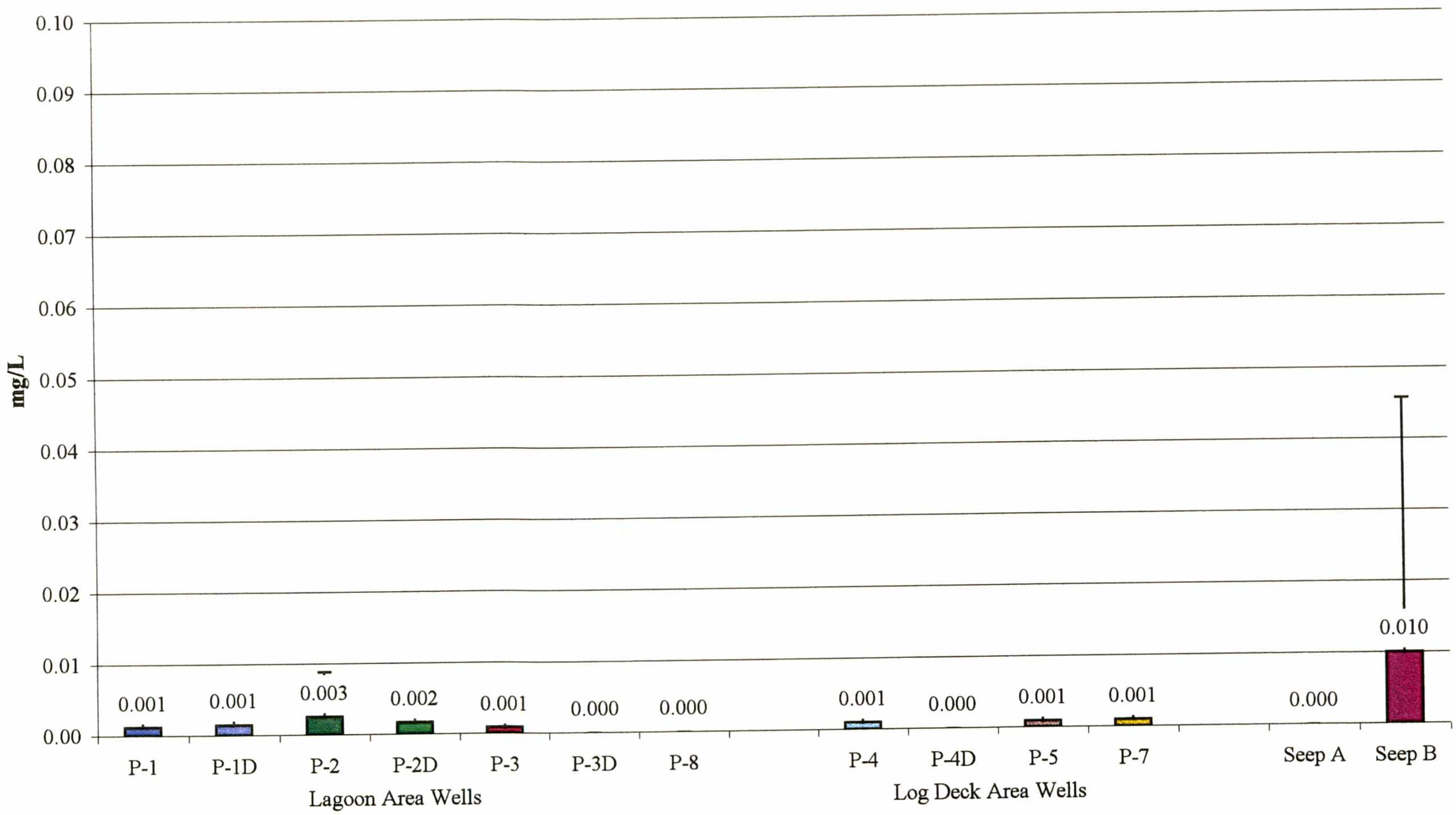
Lagoon COD mean = 1,781 mg/L
No maximum contaminant level (MCL) for this parameter
Error bars show upper 95% confidence limits

Figure 17. Mean Chloride (Cl) Concentrations (mg/L)



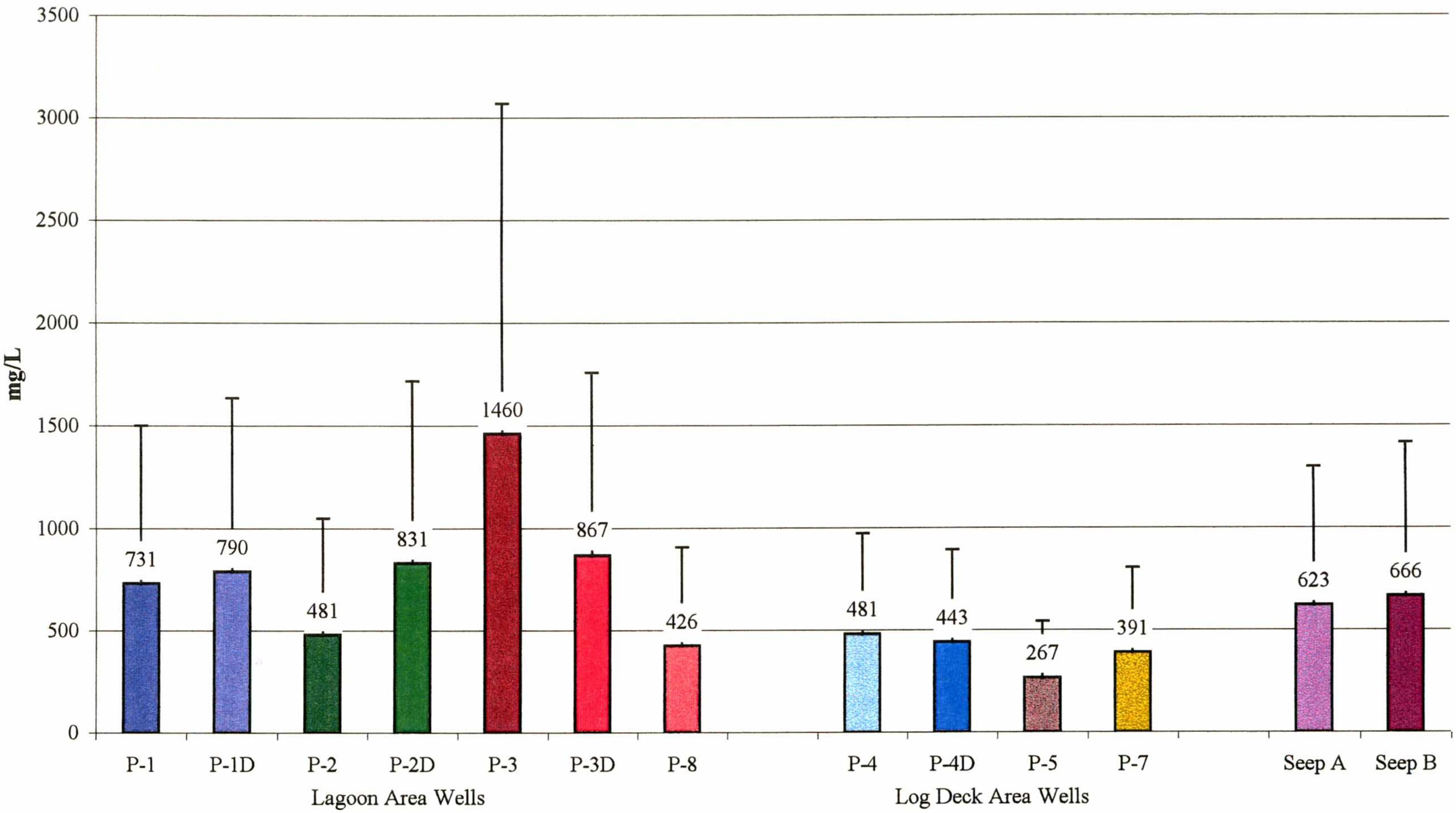
Lagoon Cl mean = 312 mg/L
Maximum contaminant level (MCL) = 250 mg/L
Error bars show upper 95% confidence limits

Figure 18. Mean Total Phenolics Concentrations (mg/L)



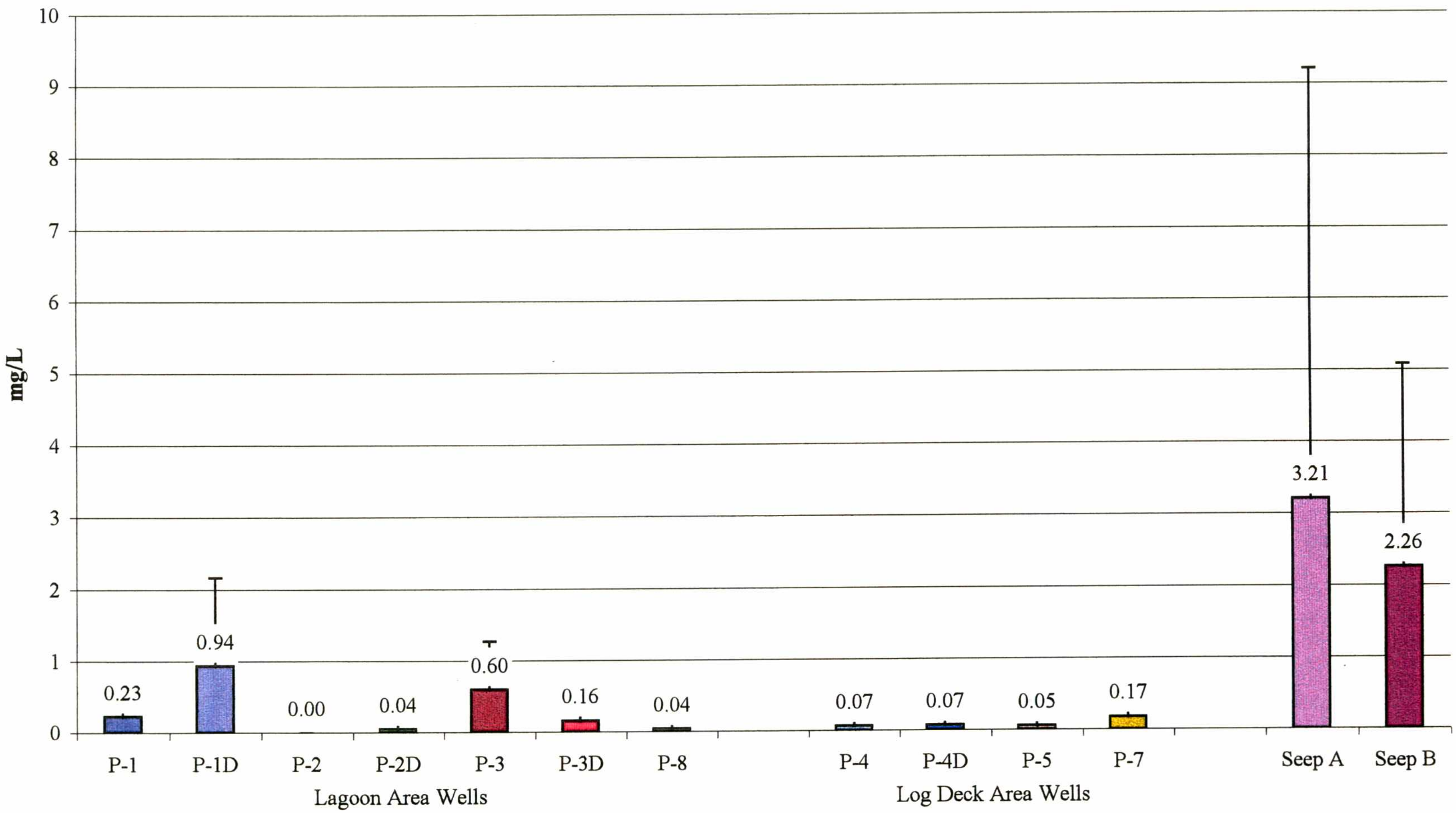
Lagoon Total Phenolics mean = 0.33 mg/L
No maximum contaminant level (MCL) for this parameter
Error bars show upper 95% confidence limits

Figure 19. Mean Total Dissolved Solids (TDS) Concentrations (mg/L)



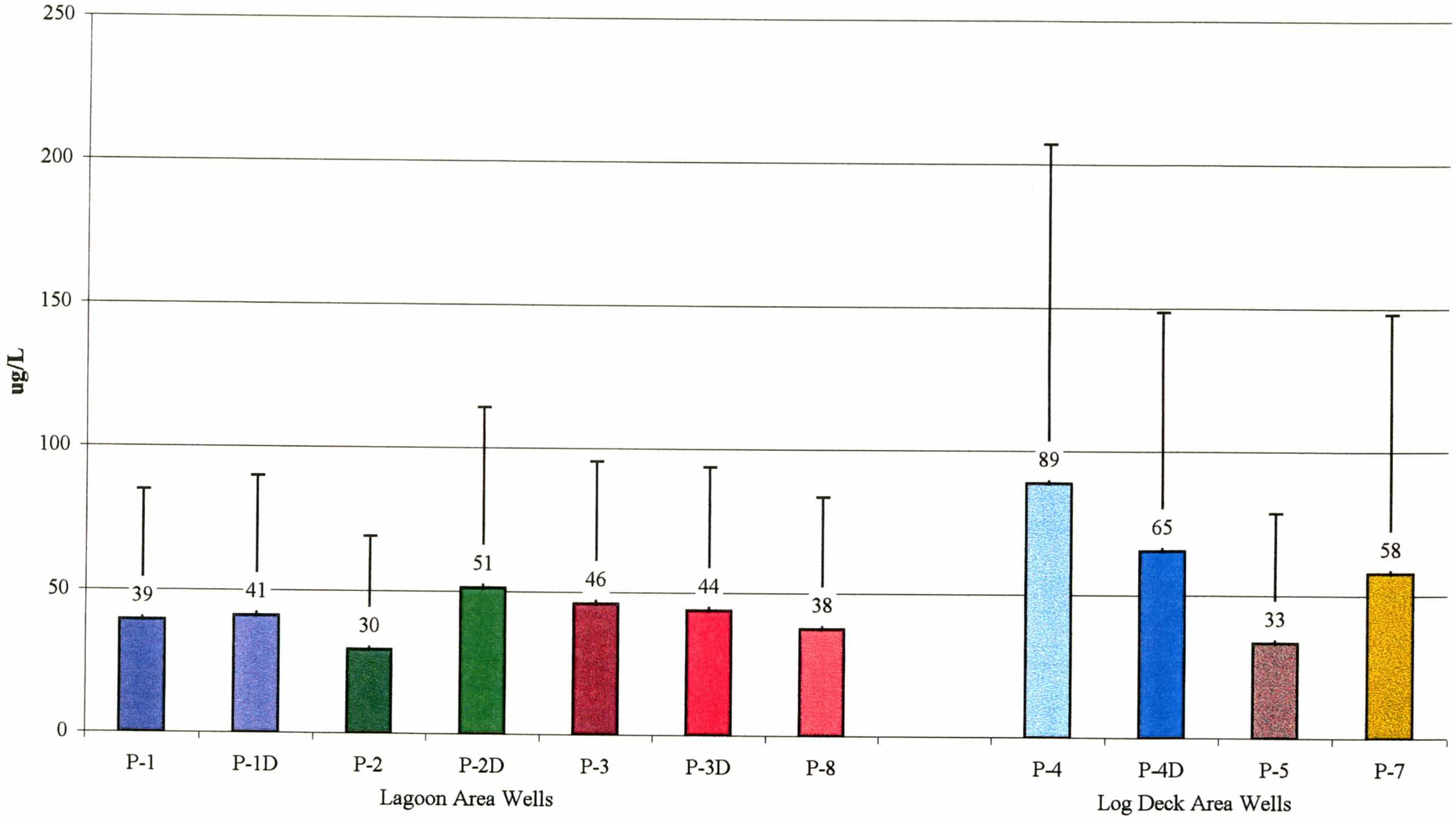
Lagoon TDS mean = 2,087 mg/L
Maximum contaminant level (MCL) = 500 mg/L
Error bars show upper 95% confidence limits

Figure 20. Mean Tannin & Lignin (T&L) Concentrations (mg/L)



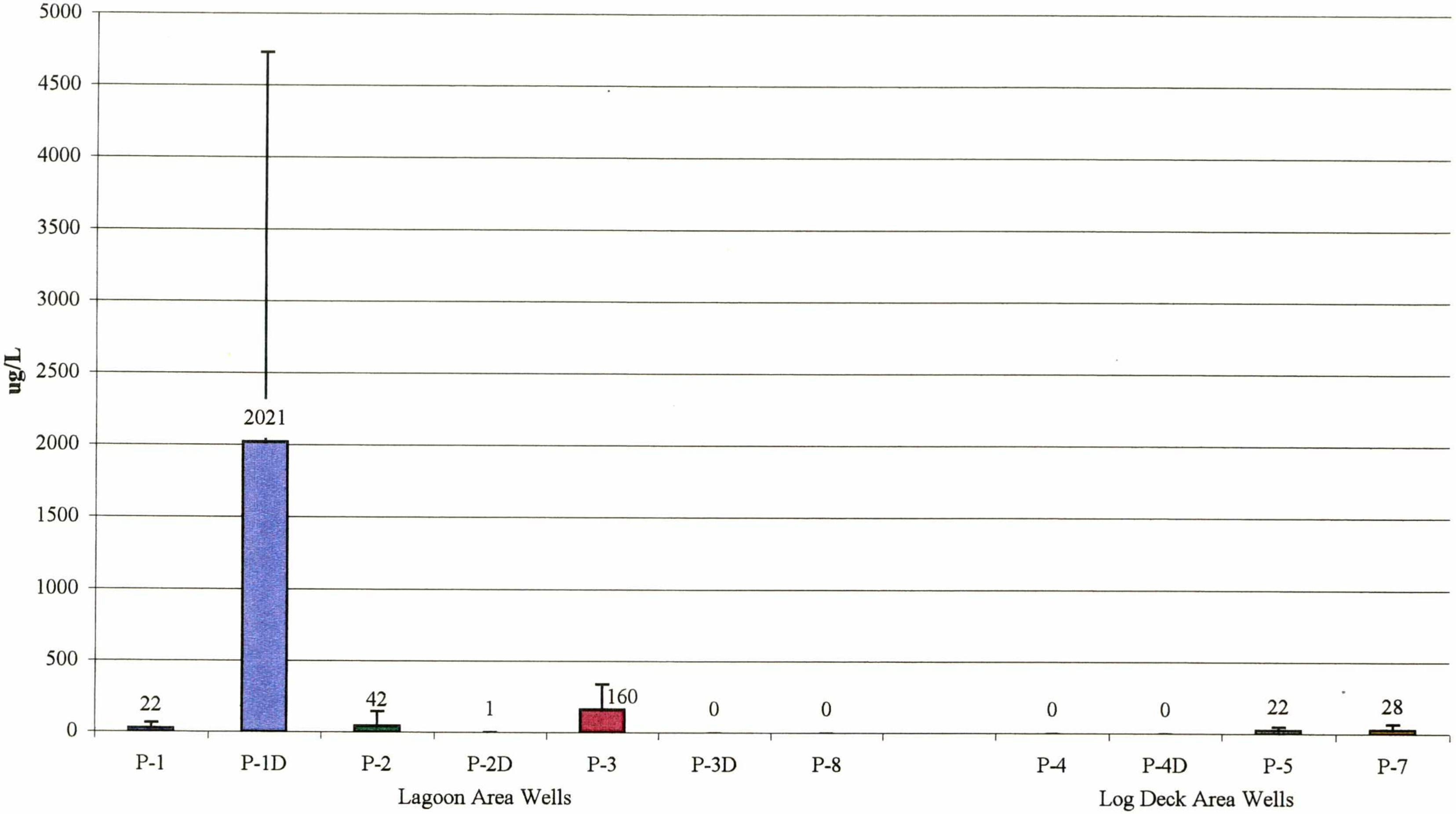
Lagoon T&L mean = 46.0 mg/L
No Maximum contaminant level (MCL) for this parameter
Error bars show upper 95% confidence limits

Figure 21. Mean Dissolved Iron (Fe) Concentrations (ug/L)



Mean <u>Total</u> Fe: Lagoon = 2,390 ug/L, Seep A = 13,962 ug/L, Seep B = 13,334 ug/L
Maximum contaminant level (MCL) = 300 ug/L (dissolved Fe)
Error bars show upper 95% confidence limits

Figure 22. Mean Dissolved Manganese (Mn) Concentrations (ug/L)



Mean Total Mn: Lagoon = 593 ug/L, Seep A = 8,939 ug/L, Seep B = 9,734 ug/L
Maximum contaminant level (MCL) = 50 ug/L (dissolved Mn)
Error bars show upper 95% confidence limits

Figure 23A. Lake Elevation Correlation with the P-1D Analytical Data Chemical Oxygen Demand (COD)

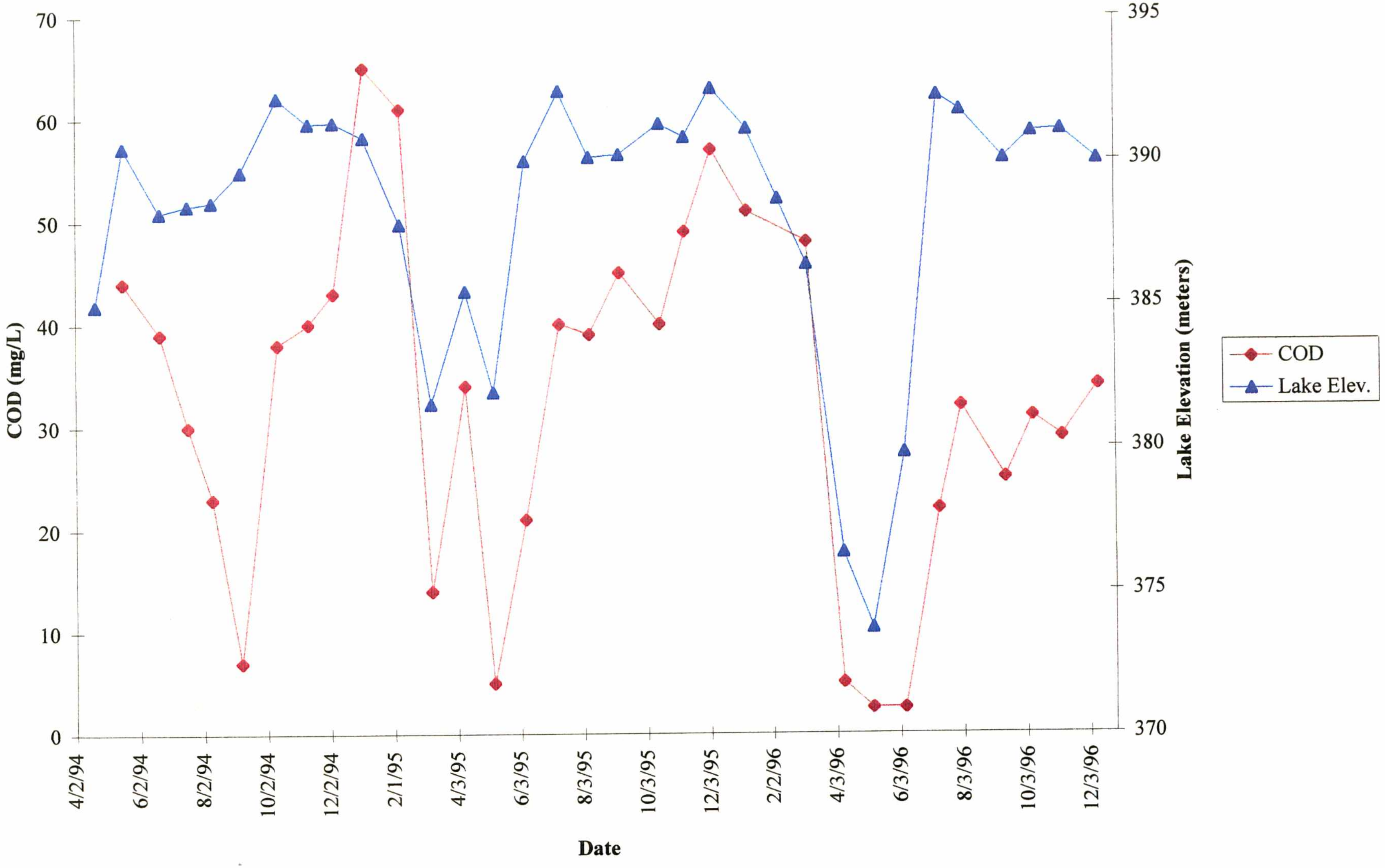


Figure 23B. Lake Elevation Correlation with the P-1D Analytical Data
Chloride (Cl) and Total Dissolved Solids (TDS)

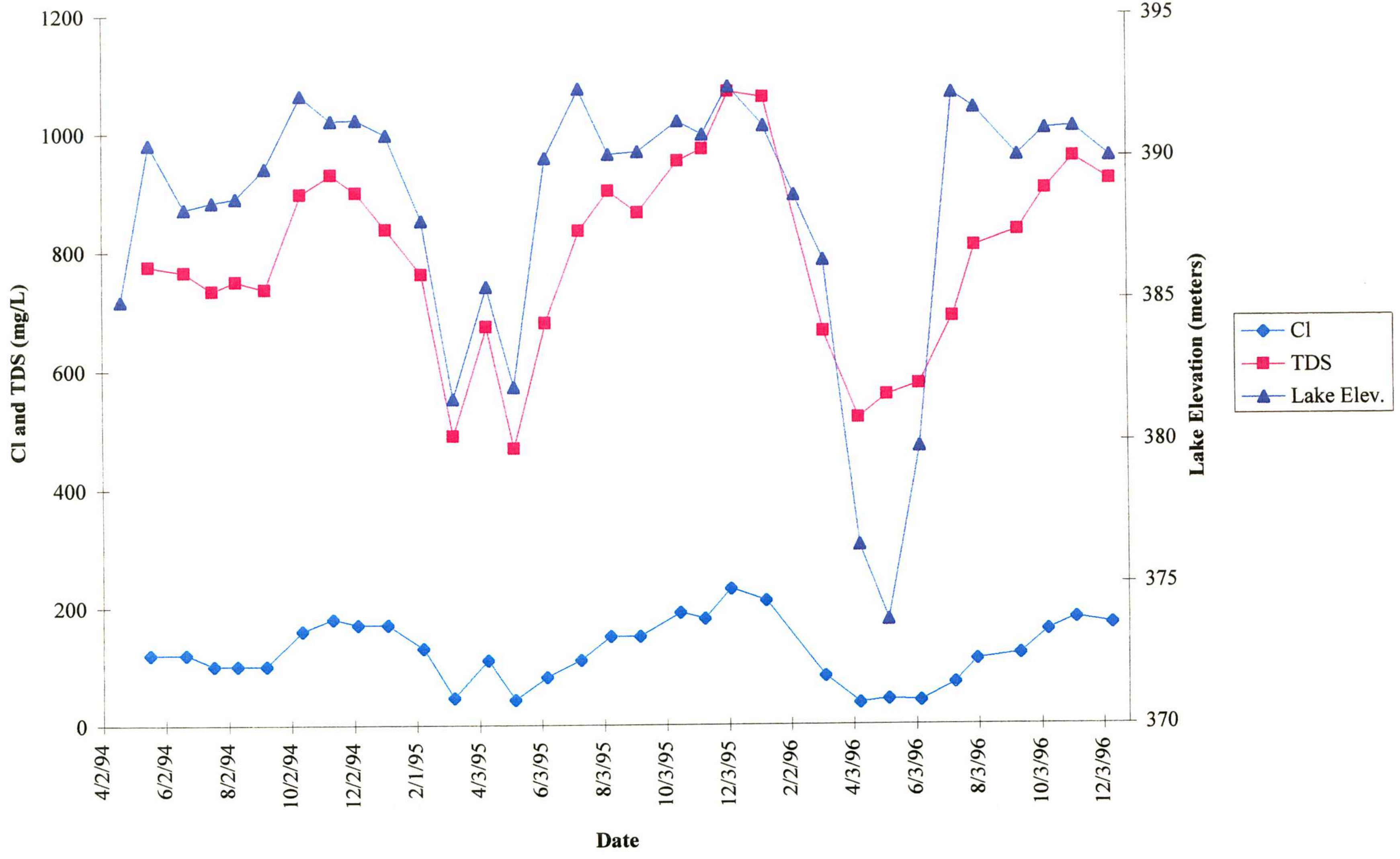


Figure 23C. Lake Elevation Correlation with the P-1D Analytical Data
Tannin & Lignin (T&L) and Dissolved Manganese (Mn)

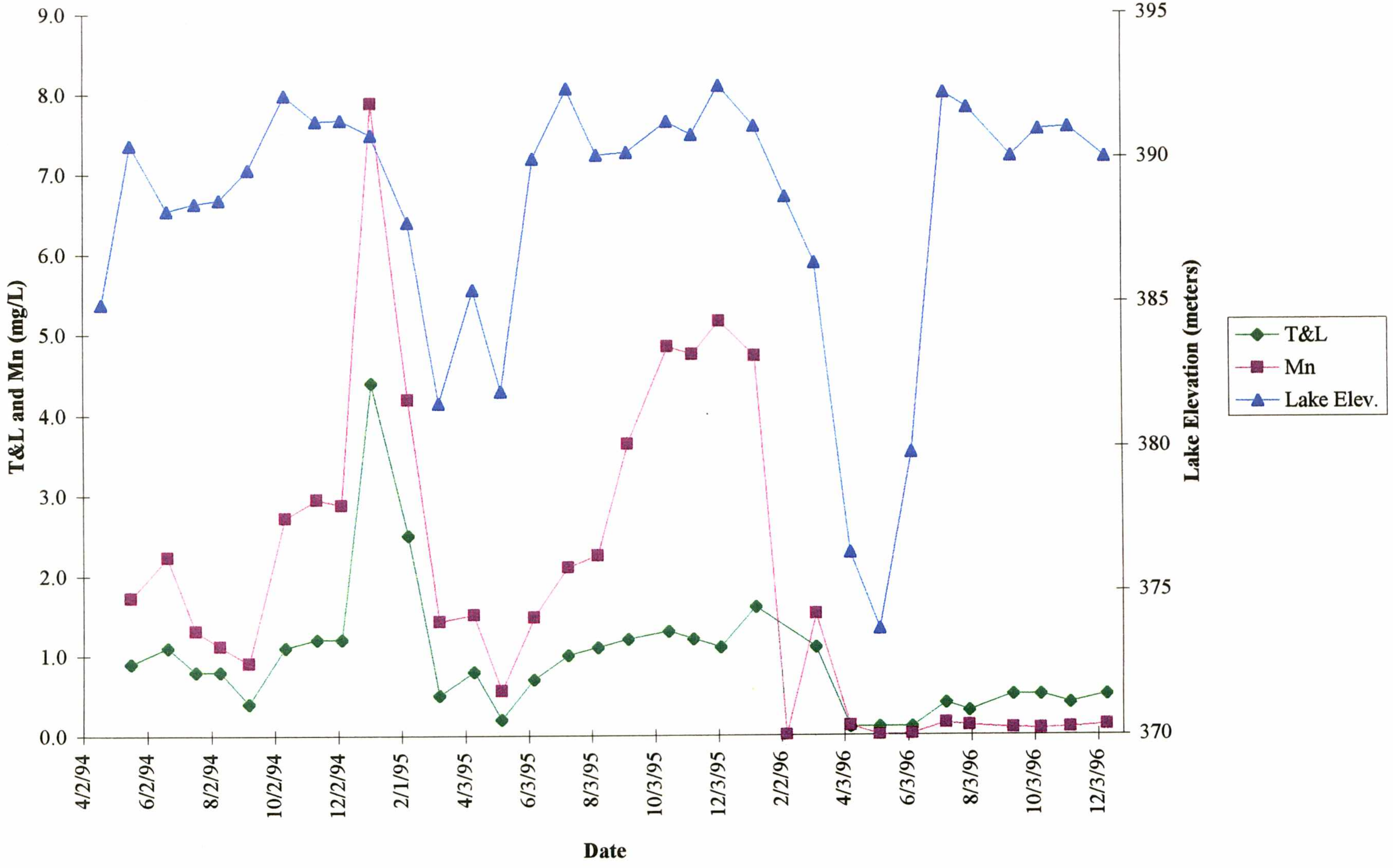


Figure 24. Negative Lake Elevation Correlation with the P-2D Analytical Data Chloride (Cl)

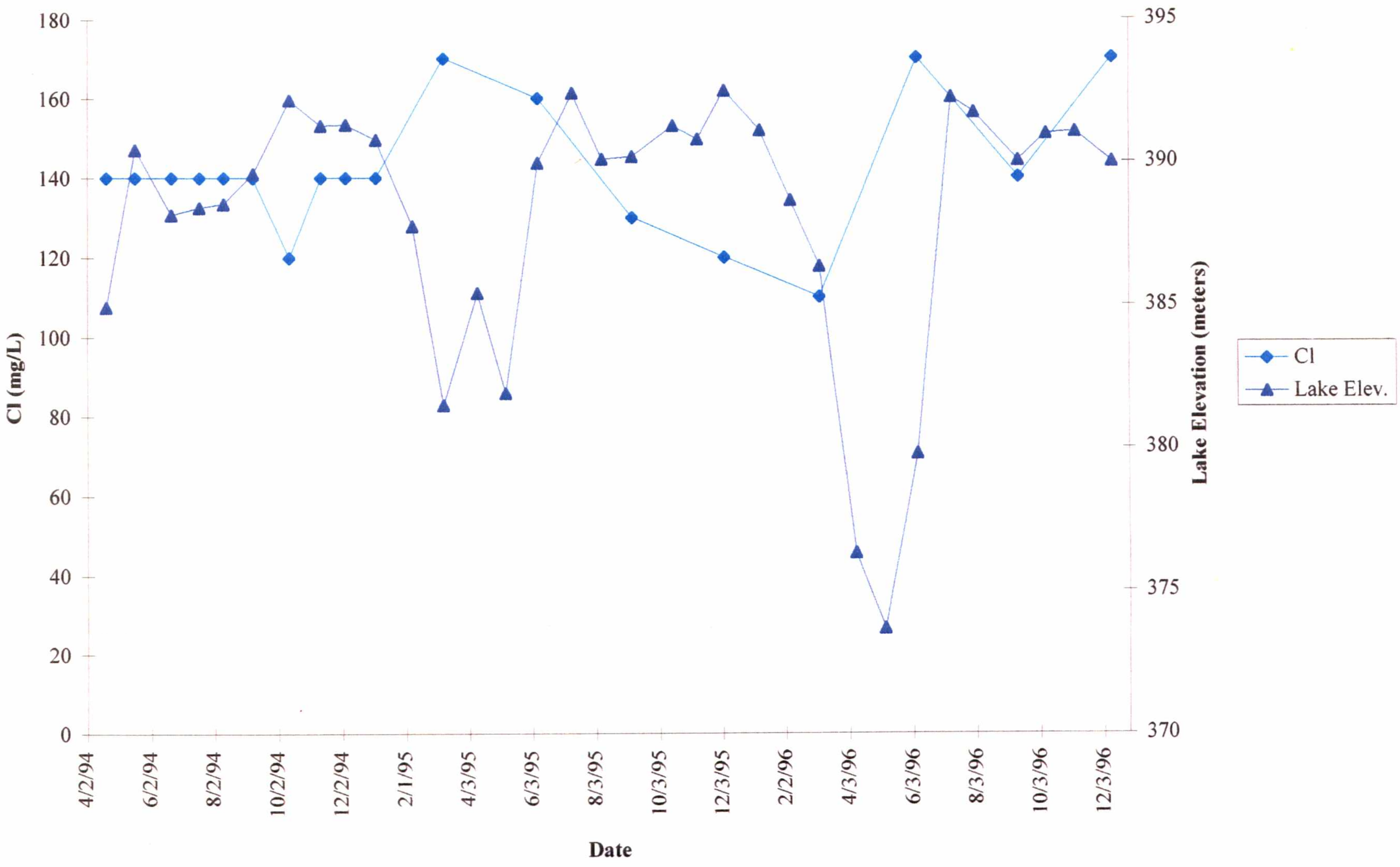


Figure 25A. Negative Lake Elevation Correlation with the P-3D Analytical Data Chemical Oxygen Demand (COD)

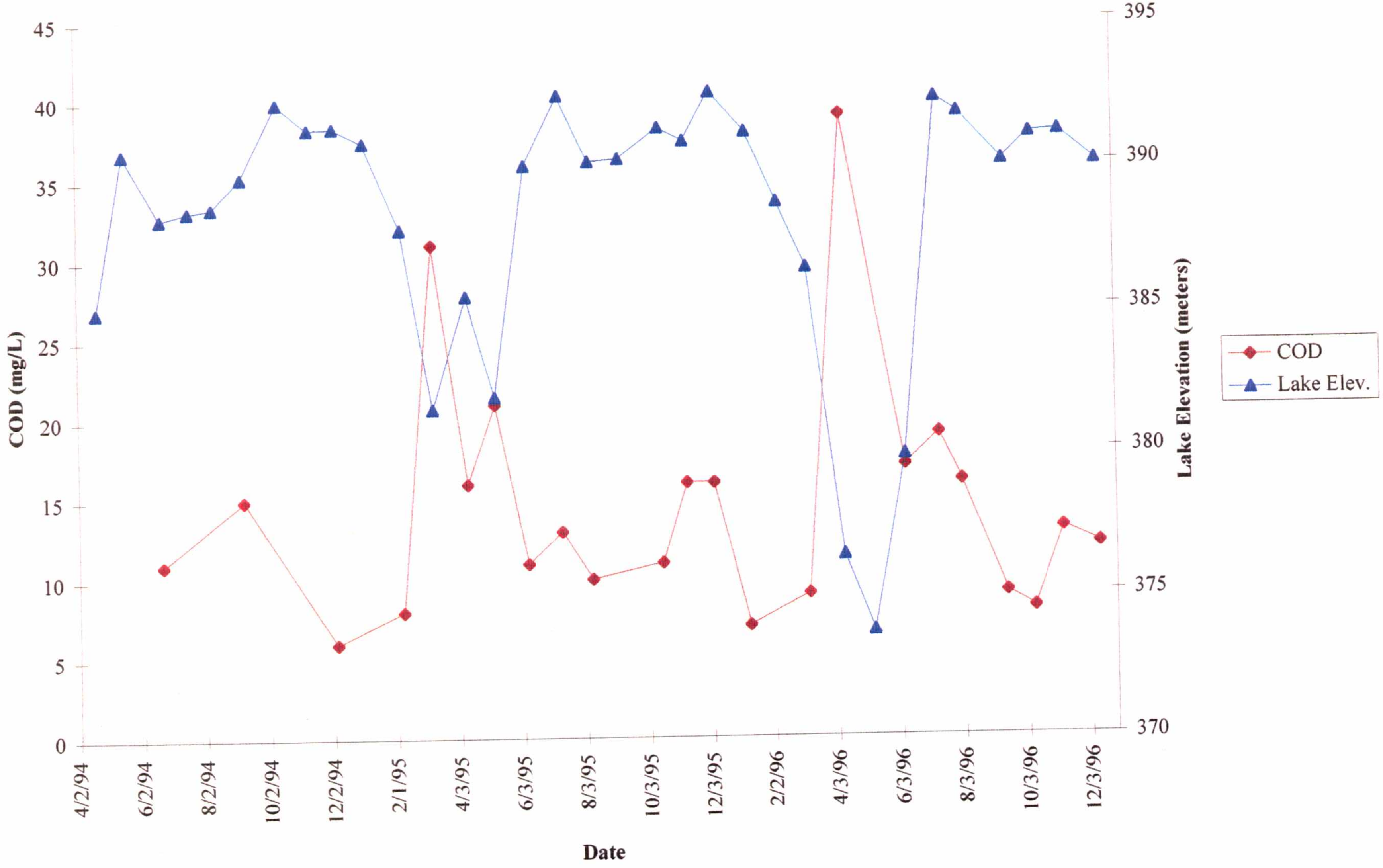


Figure 25B. Negative Lake Elevation Correlation with the P-3D Analytical Data Chloride (Cl)

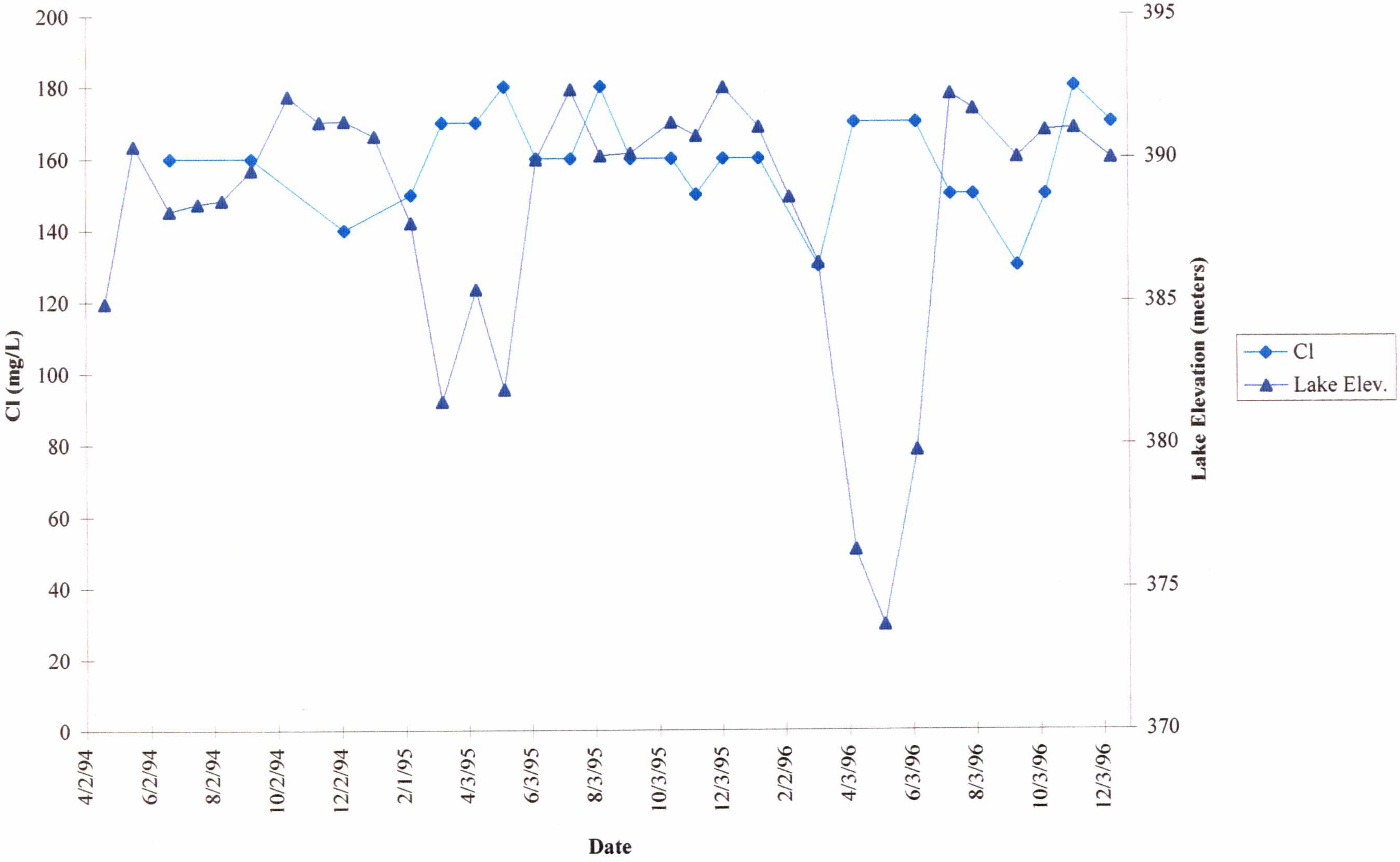


Figure 25C. Negative Lake Elevation Correlation with the P-3D Analytical Data
Total Dissolved Solids (TDS)

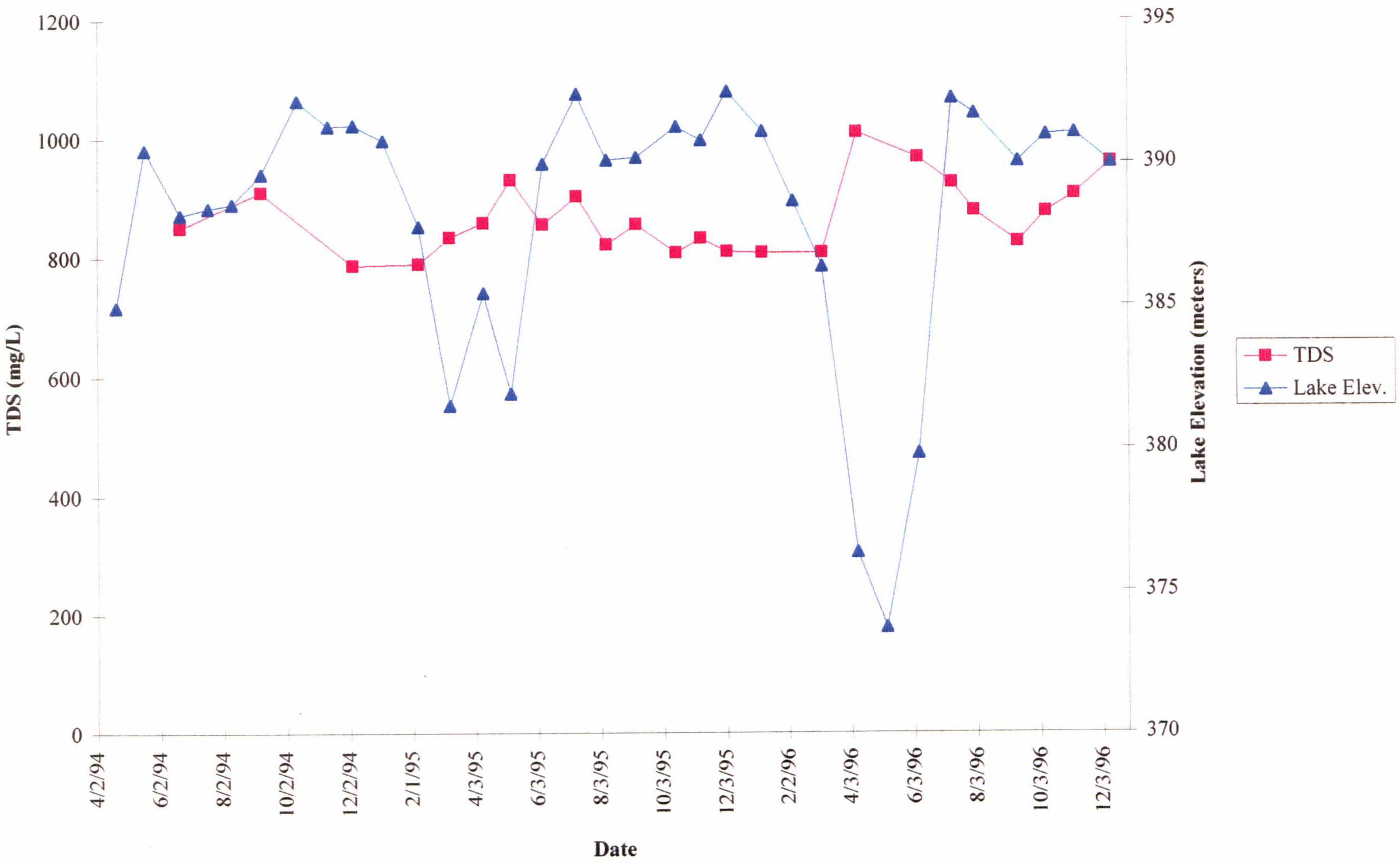


Figure 25D. Negative Lake Elevation Correlation with the P-3D Analytical Data Tannin & Lignin (T&L)

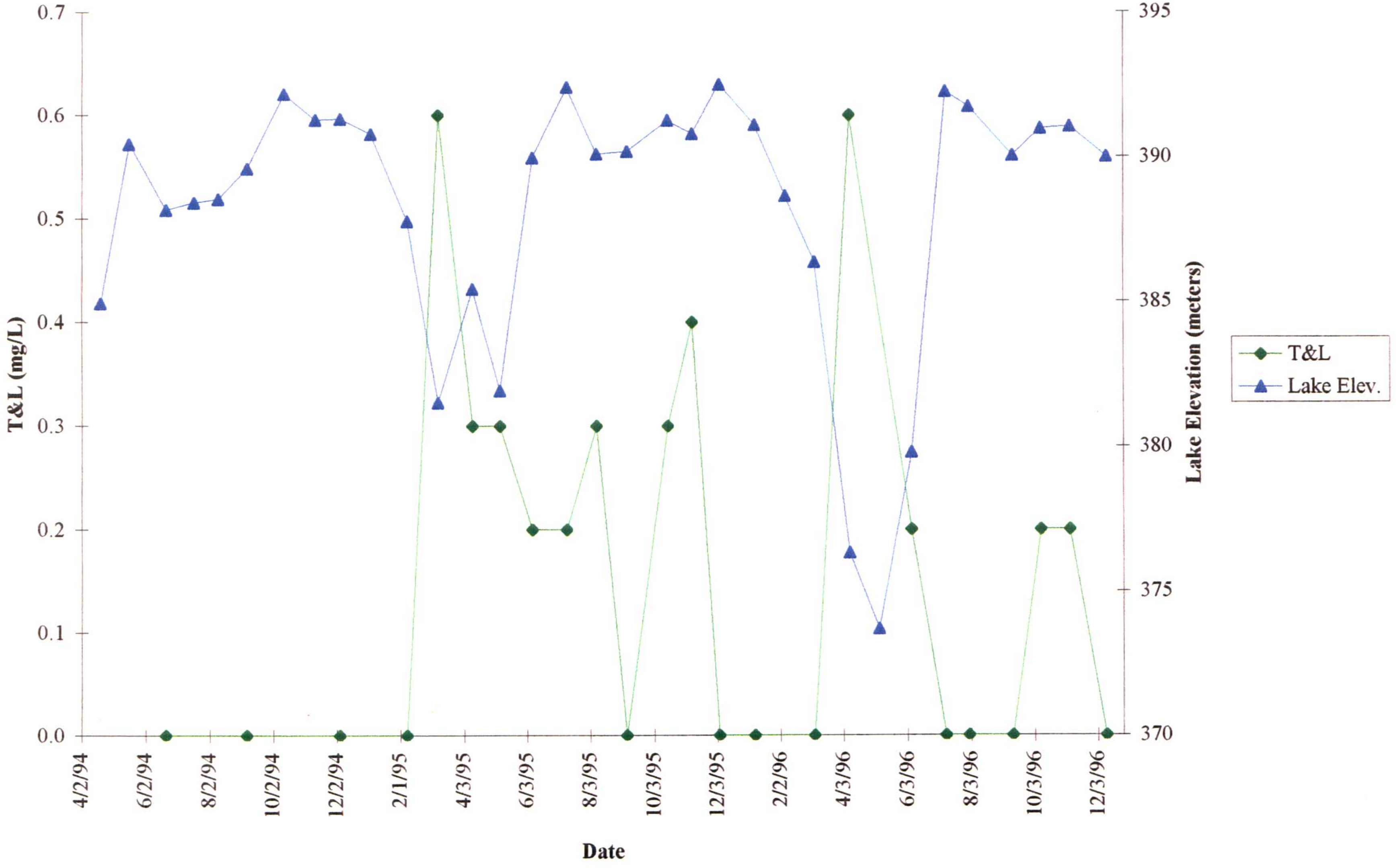


Figure 26. Negative Lake Elevation Correlation with the P-1 Analytical Data Total Dissolved Solids (TDS)

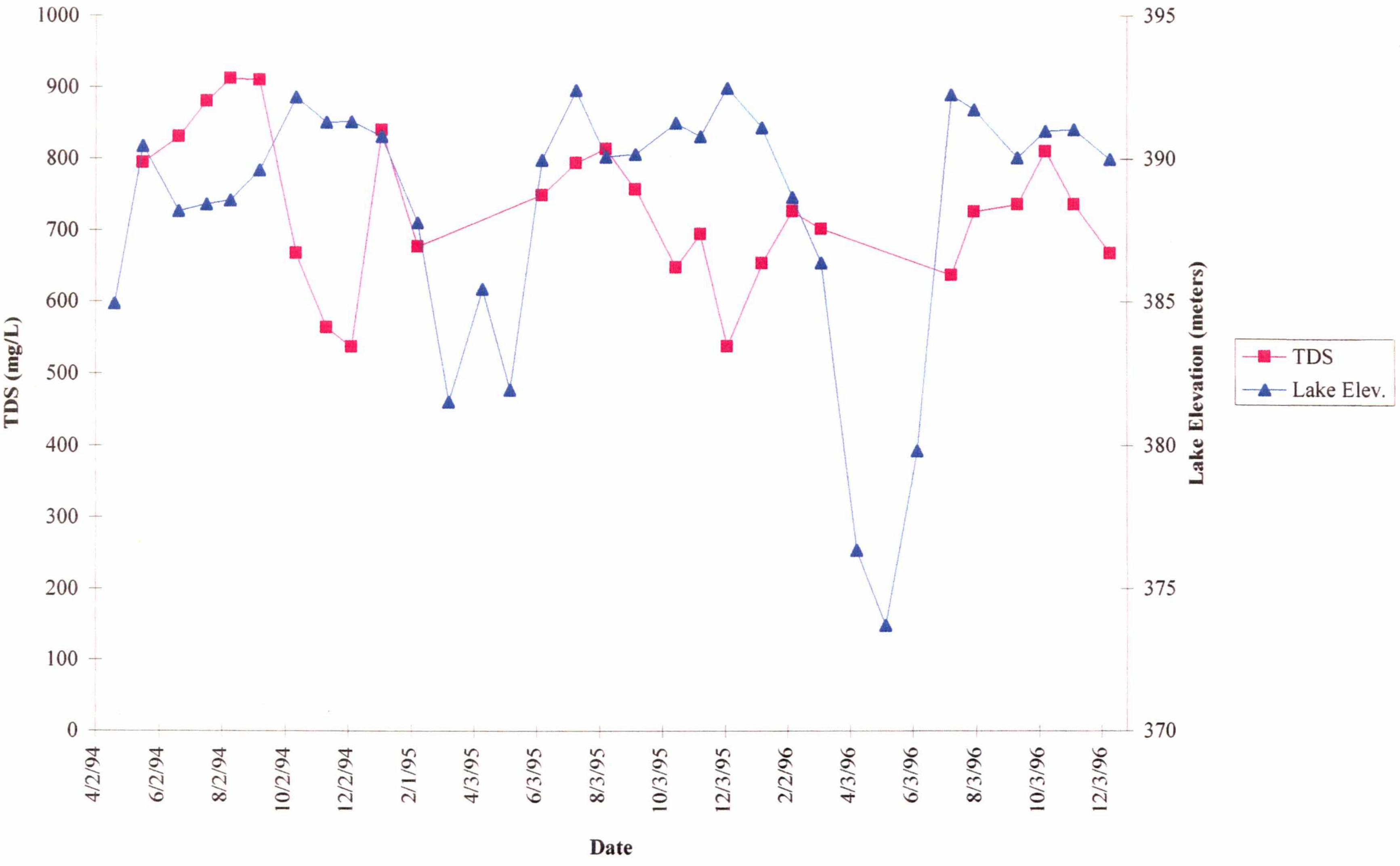


Figure 27. Temporal Trends in Groundwater Chemical Oxygen Demand (COD) Concentrations
(wells with statistically-significant temporal trends)

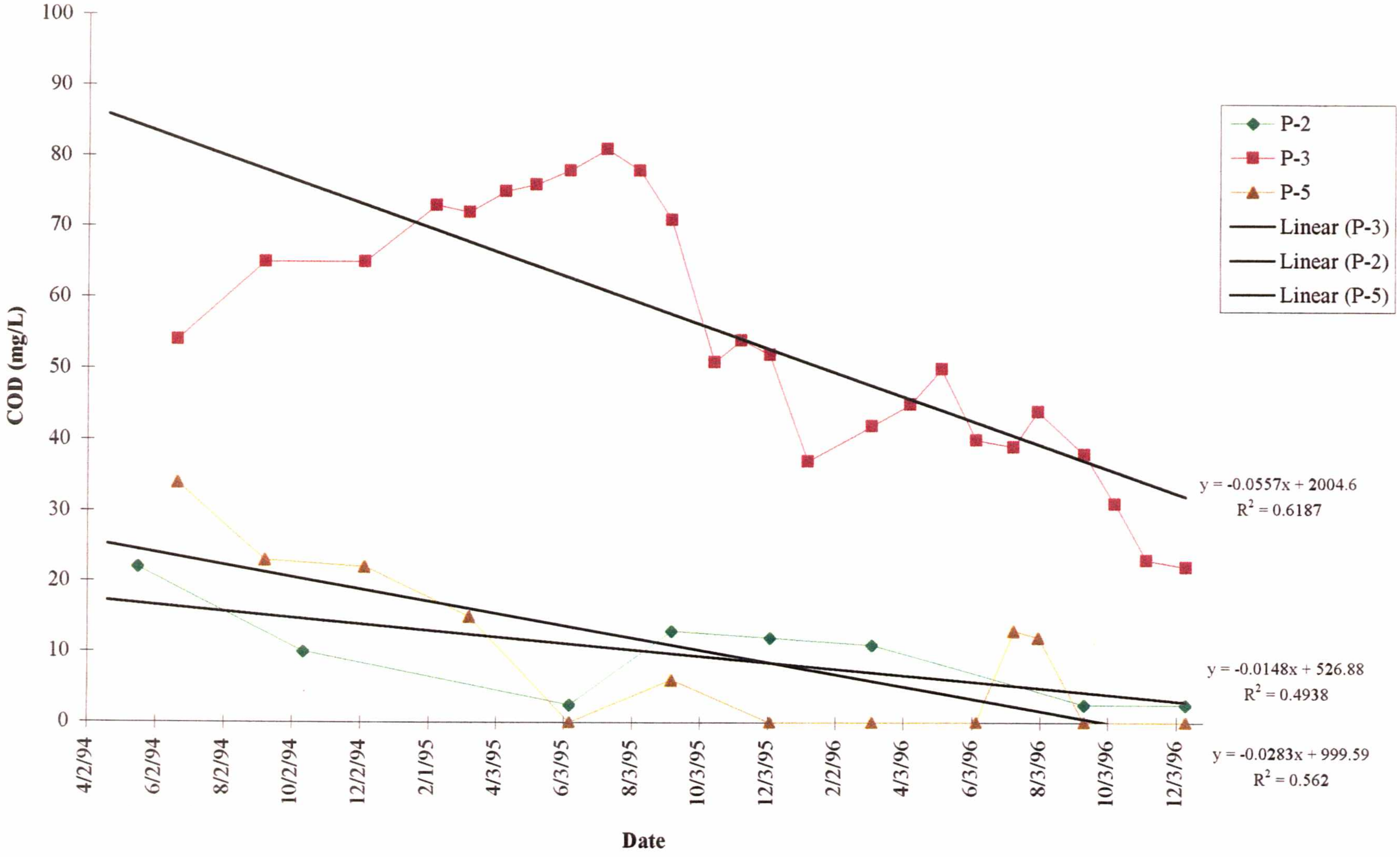


Figure 28A. Temporal Trends in Groundwater Chloride (Cl) Concentrations
(wells with statistically-significant temporal trends)

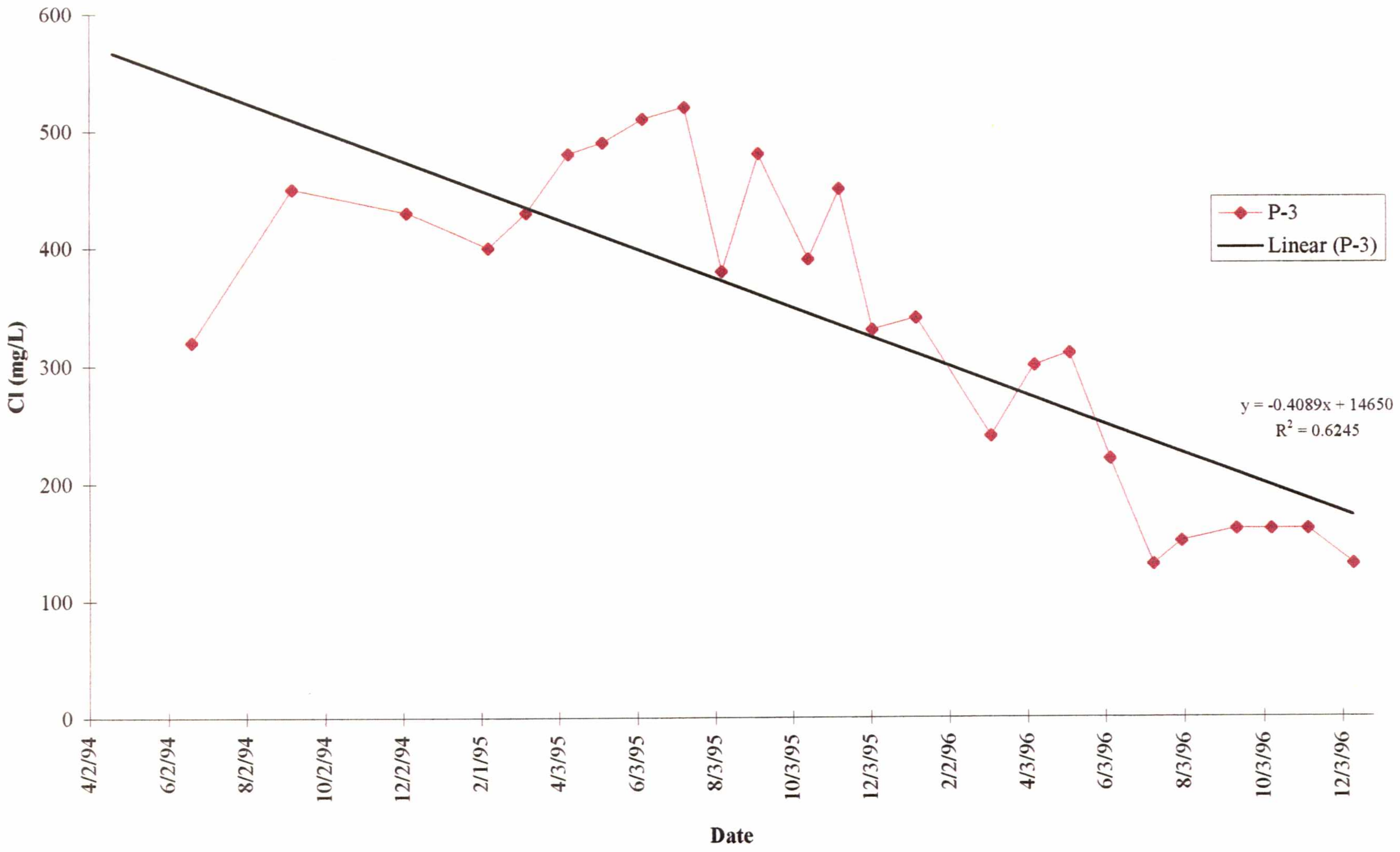


Figure 28B. Temporal Trends in Groundwater Chloride (Cl) Concentrations (wells with statistically-significant temporal trends)

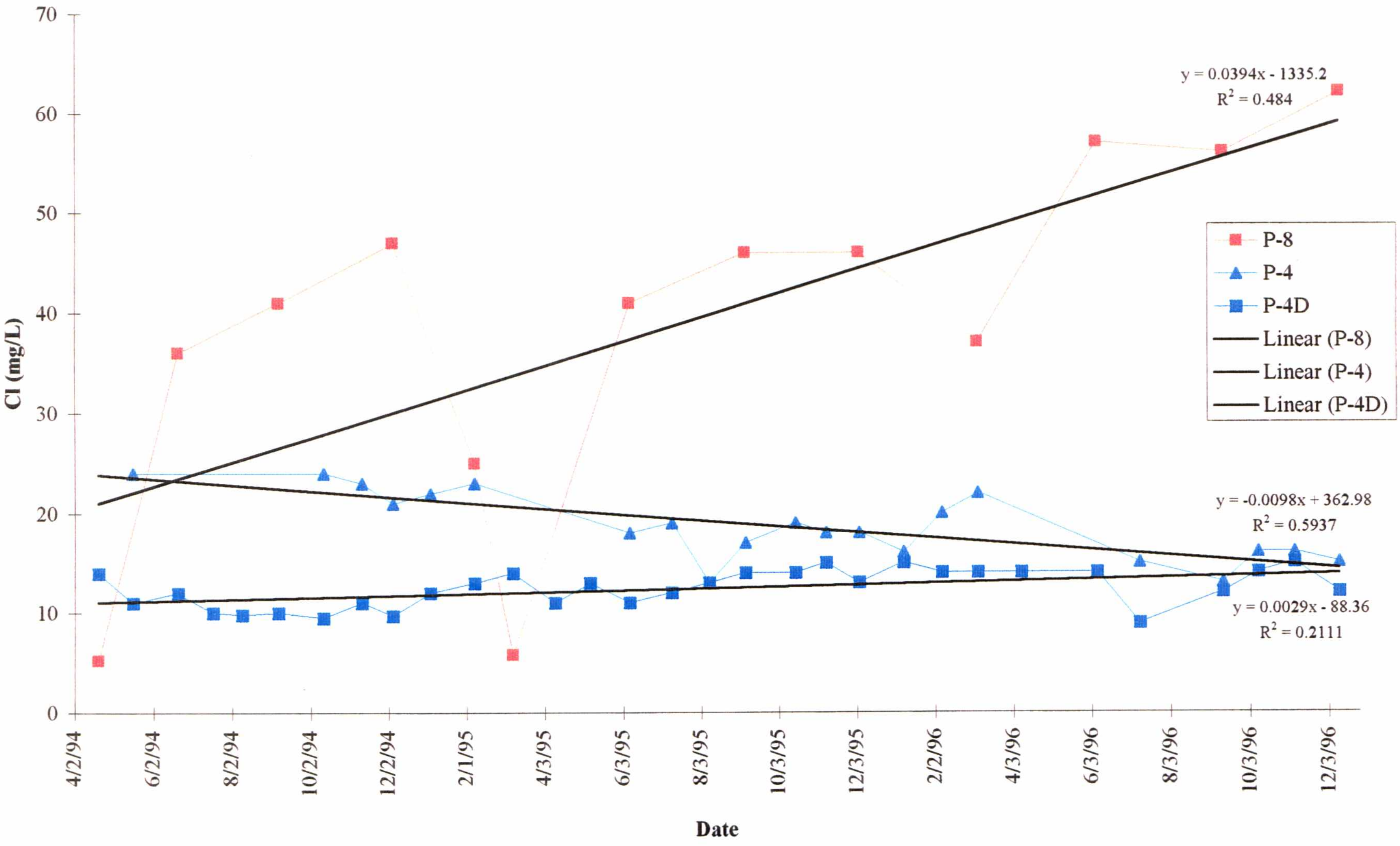


Figure 29A. Temporal Trends in Groundwater Total Dissolved Solids (TDS) Concentrations (wells with statistically-significant temporal trends)

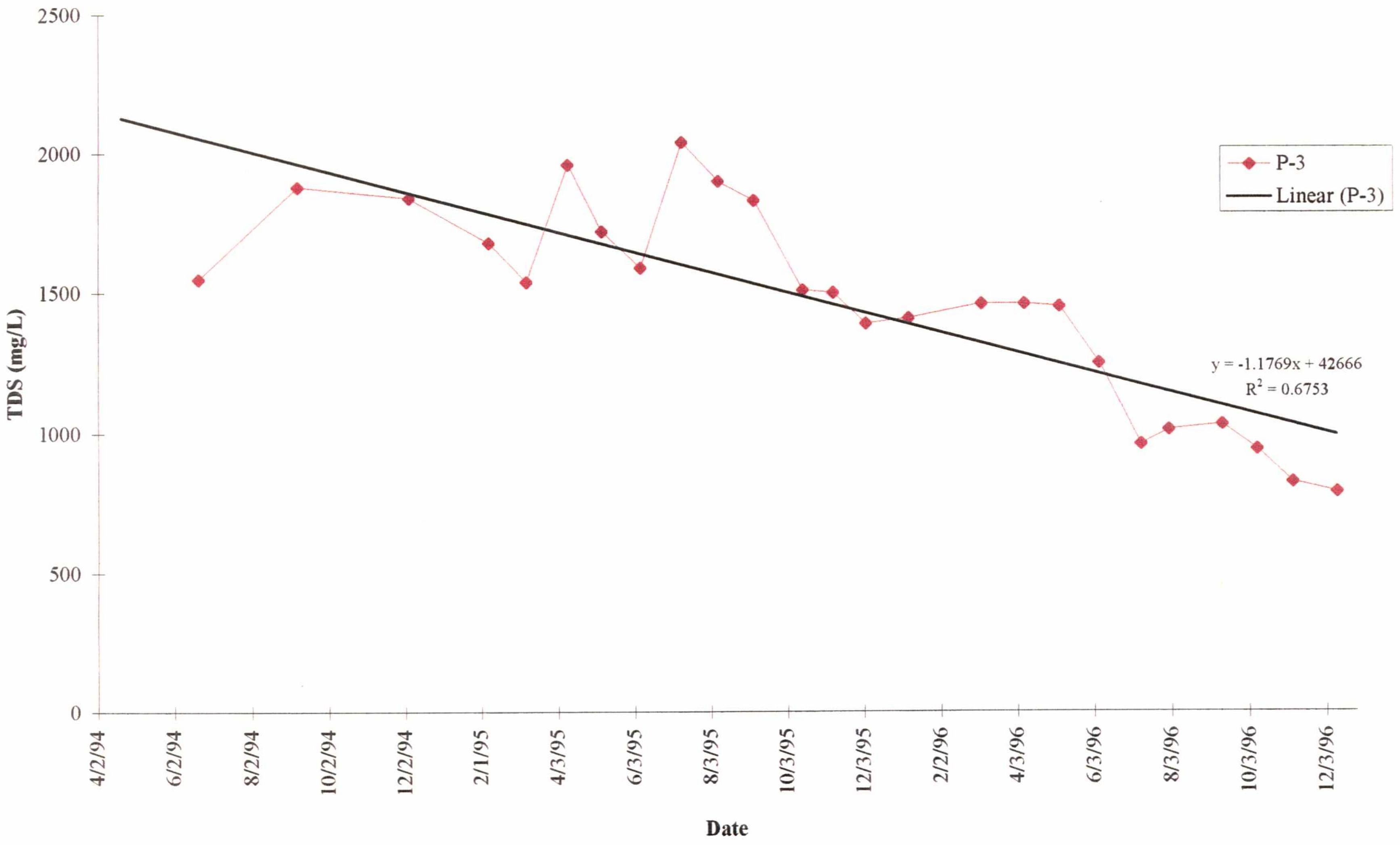


Figure 29B. Temporal Trends in Groundwater Total Dissolved Solids (TDS) Concentrations (wells with statistically-significant temporal trends)

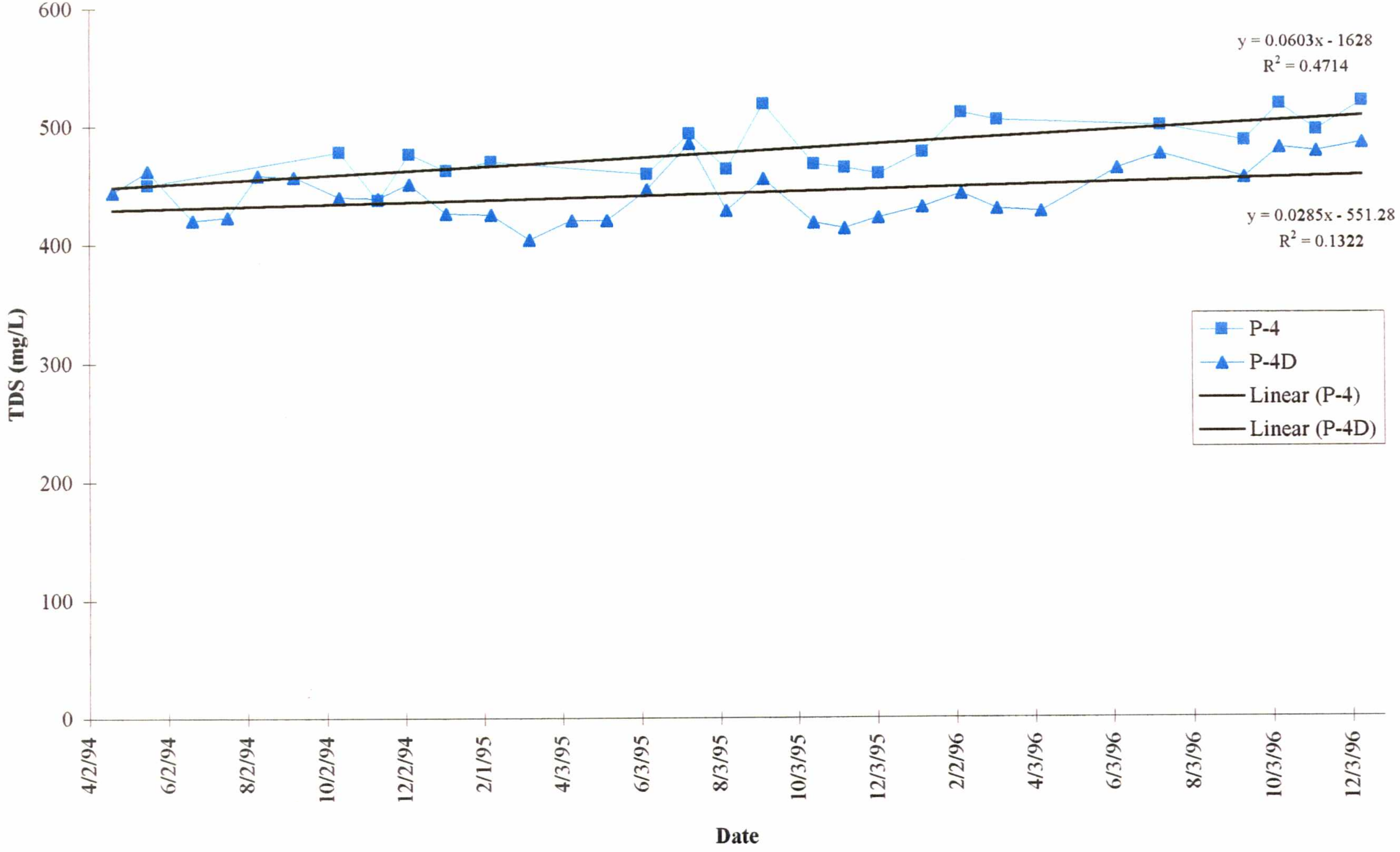


Figure 30A. Temporal Trends in Groundwater Tannin & Lignin (T&L) Concentrations
(wells with statistically-significant temporal trends)

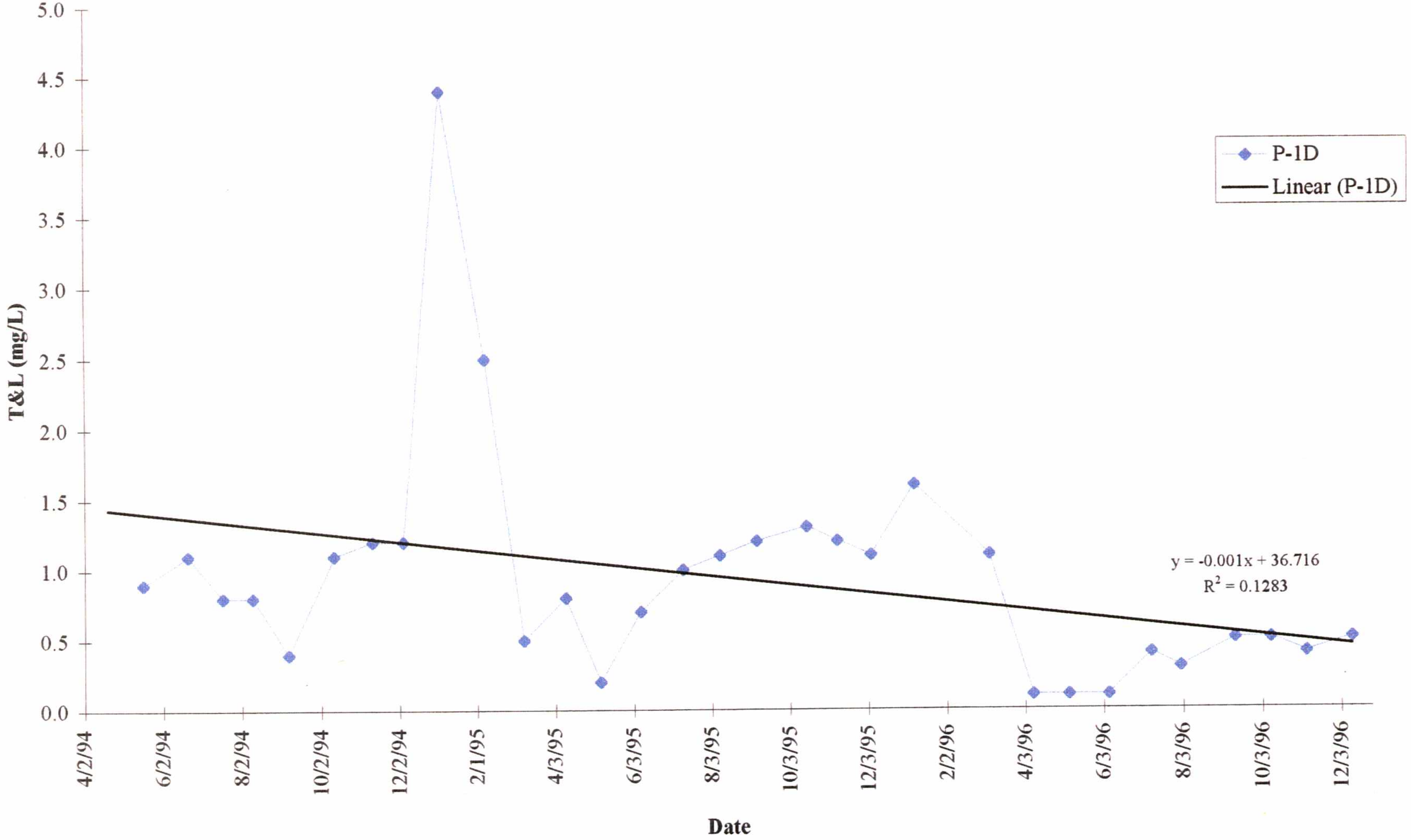


Figure 30B. Temporal Trends in Groundwater Tannin & Lignin (T&L) Concentrations (wells with statistically-significant temporal trends)

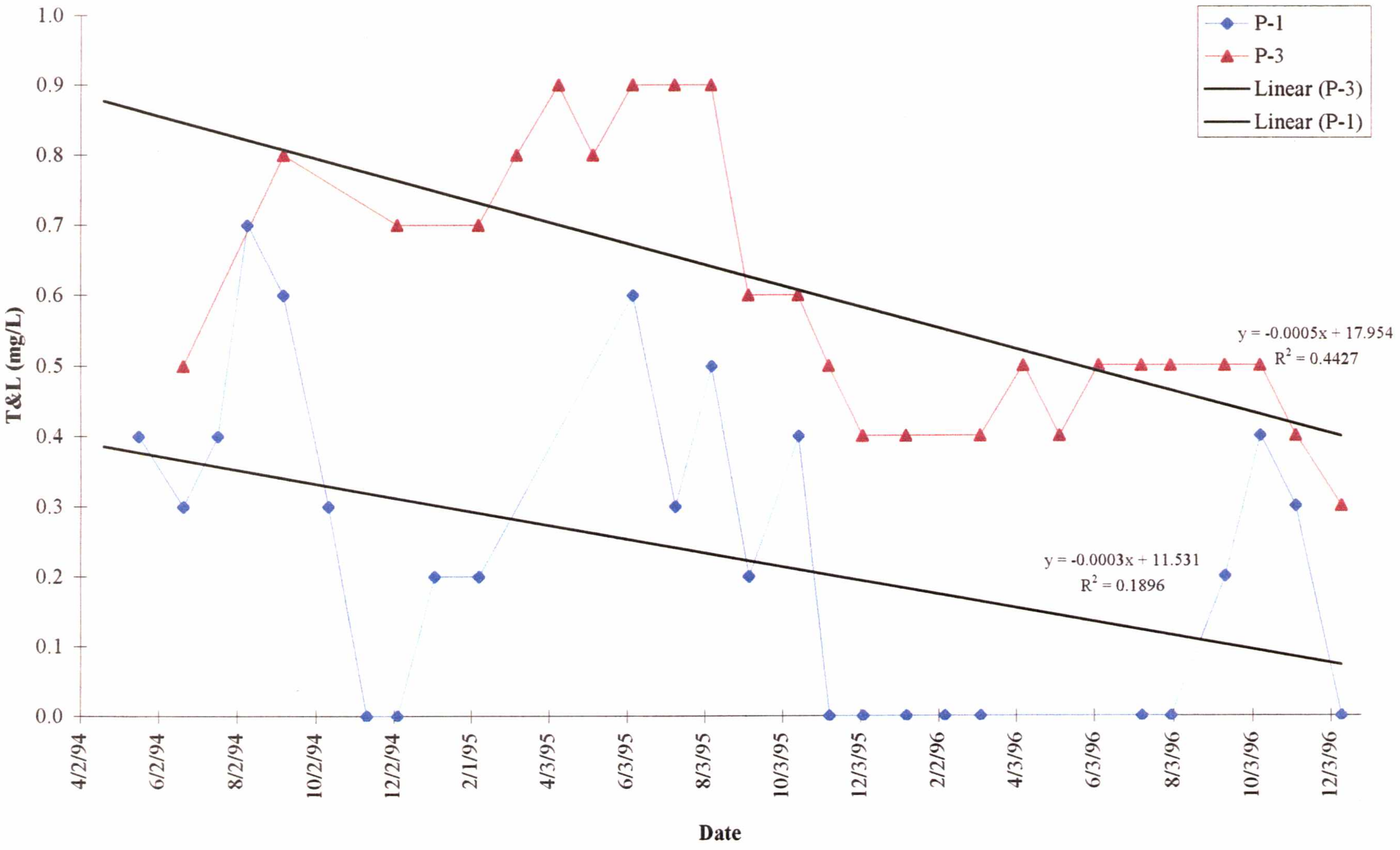


Figure 31. Temporal Trends in Groundwater Dissolved Iron (Fe) Concentrations
(wells with statistically-significant temporal trends)

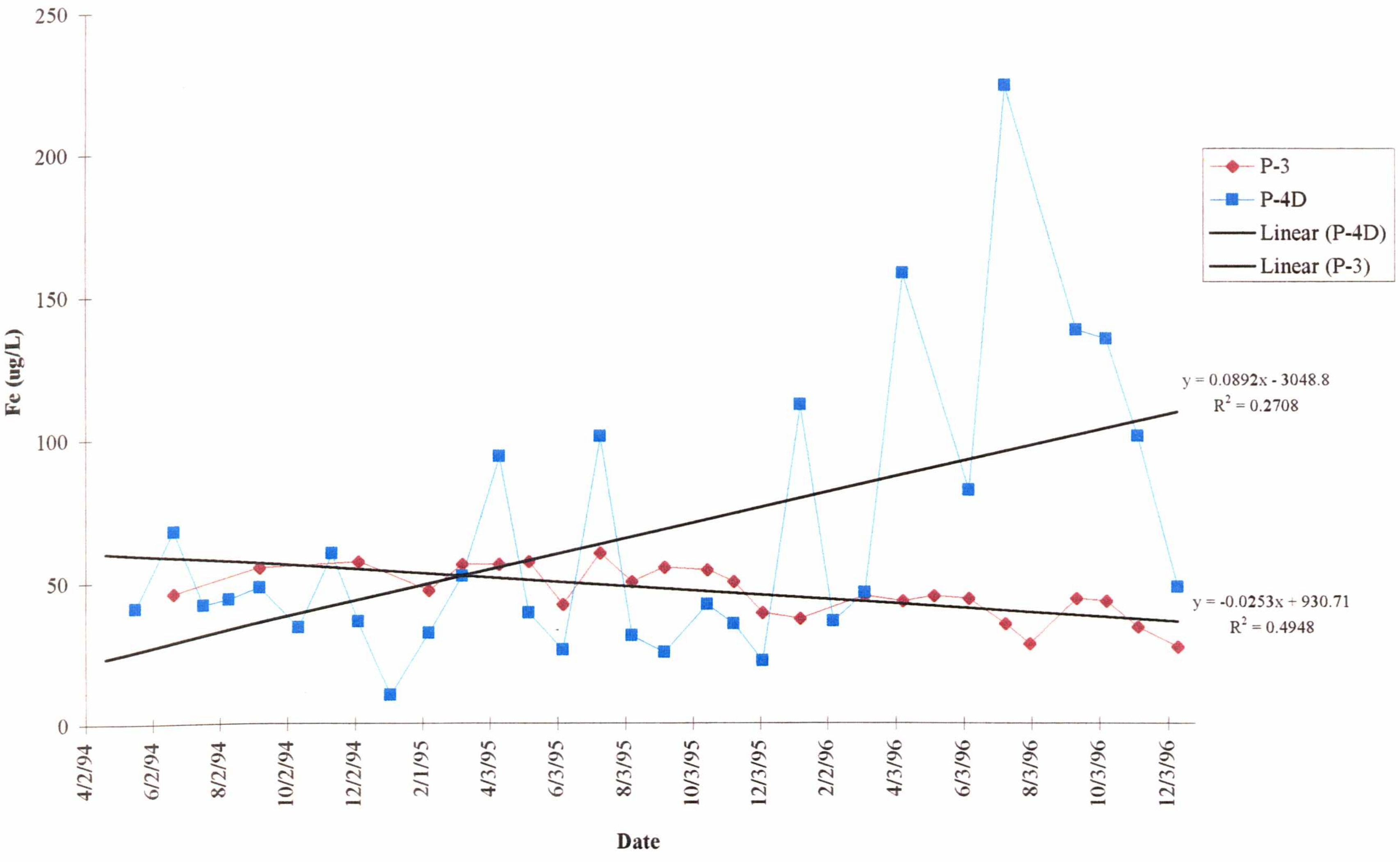


Figure 32A. Temporal Trends in Groundwater Dissolved Manganese (Mn) Concentrations
(wells with statistically-significant temporal trends)

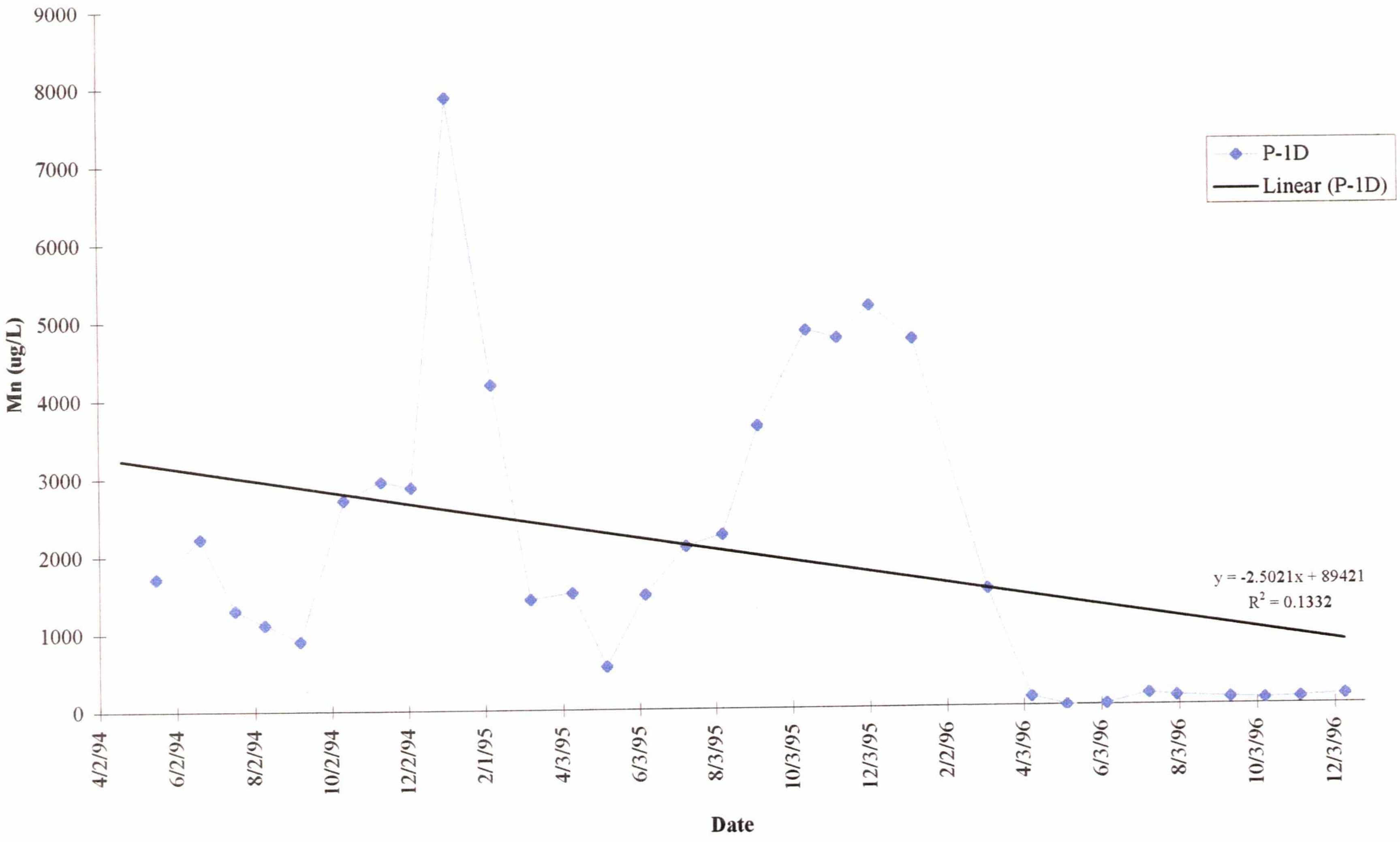


Figure 32B. Temporal Trends in Groundwater Dissolved Manganese (Mn) Concentrations
(wells with statistically-significant temporal trends)

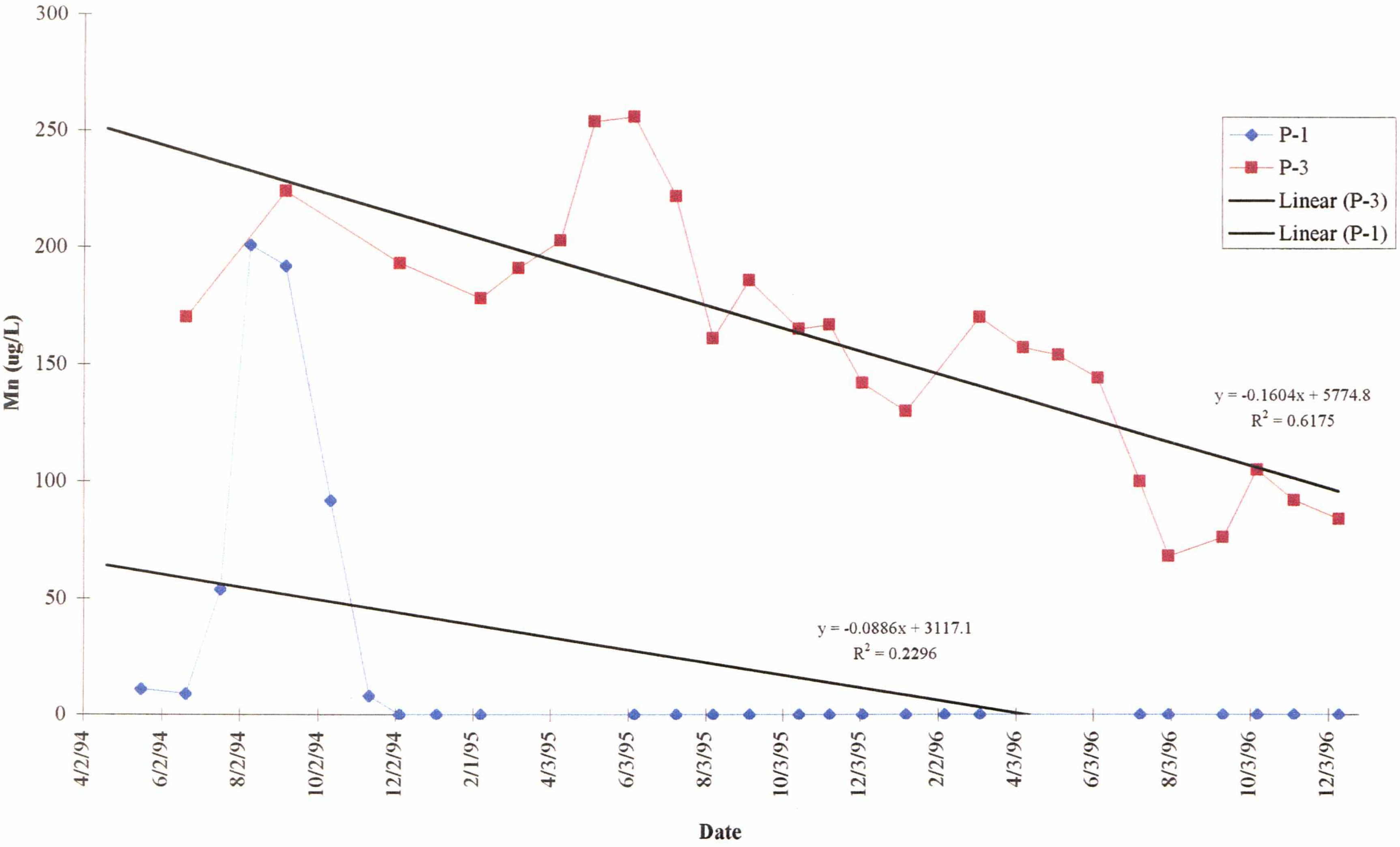


Figure 32C. Temporal Trends in Groundwater Dissolved Manganese (Mn) Concentrations (wells with statistically-significant temporal trends)

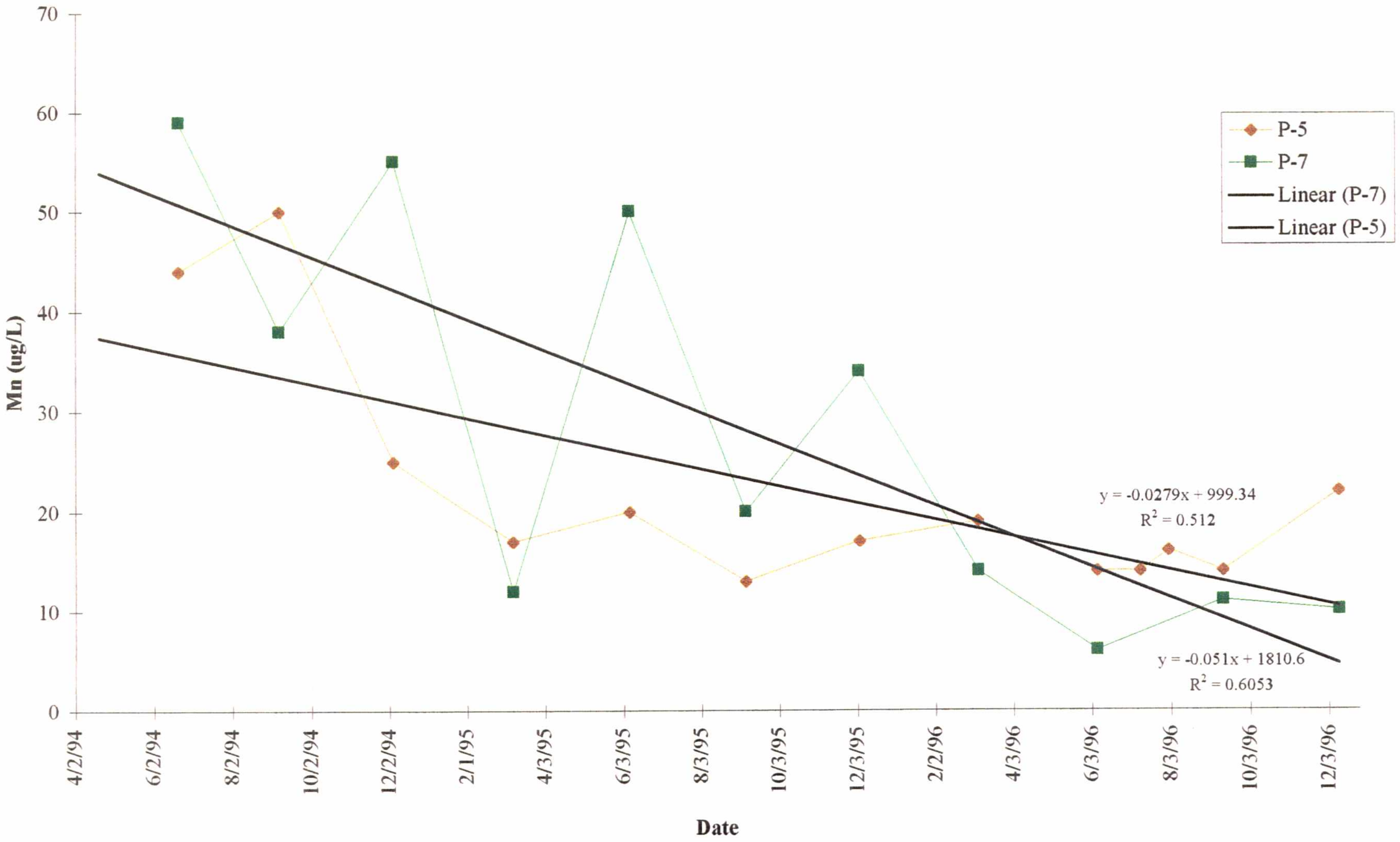


Figure 33. Temporal Trends in Seep A Analytical Data
Chemical Oxygen Demand (COD) & Chloride (Cl)
(analytes with statistically-significant temporal trends)

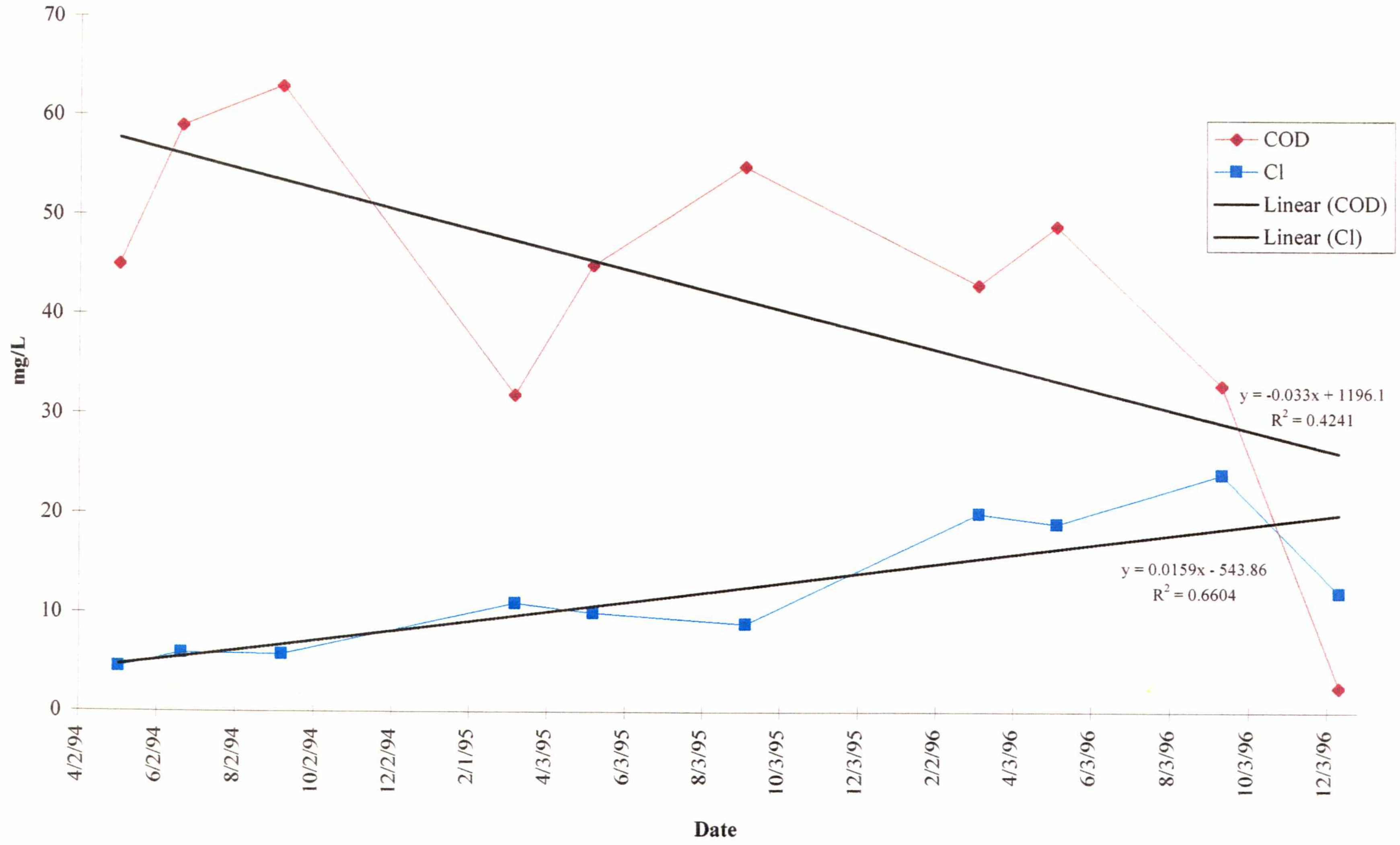


Figure 34A. Temporal Trends in Lagoon Analytical Data
Chemical Oxygen Demand (COD) & Total Dissolved Solids (TDS)
(analytes with statistically-significant temporal trends)

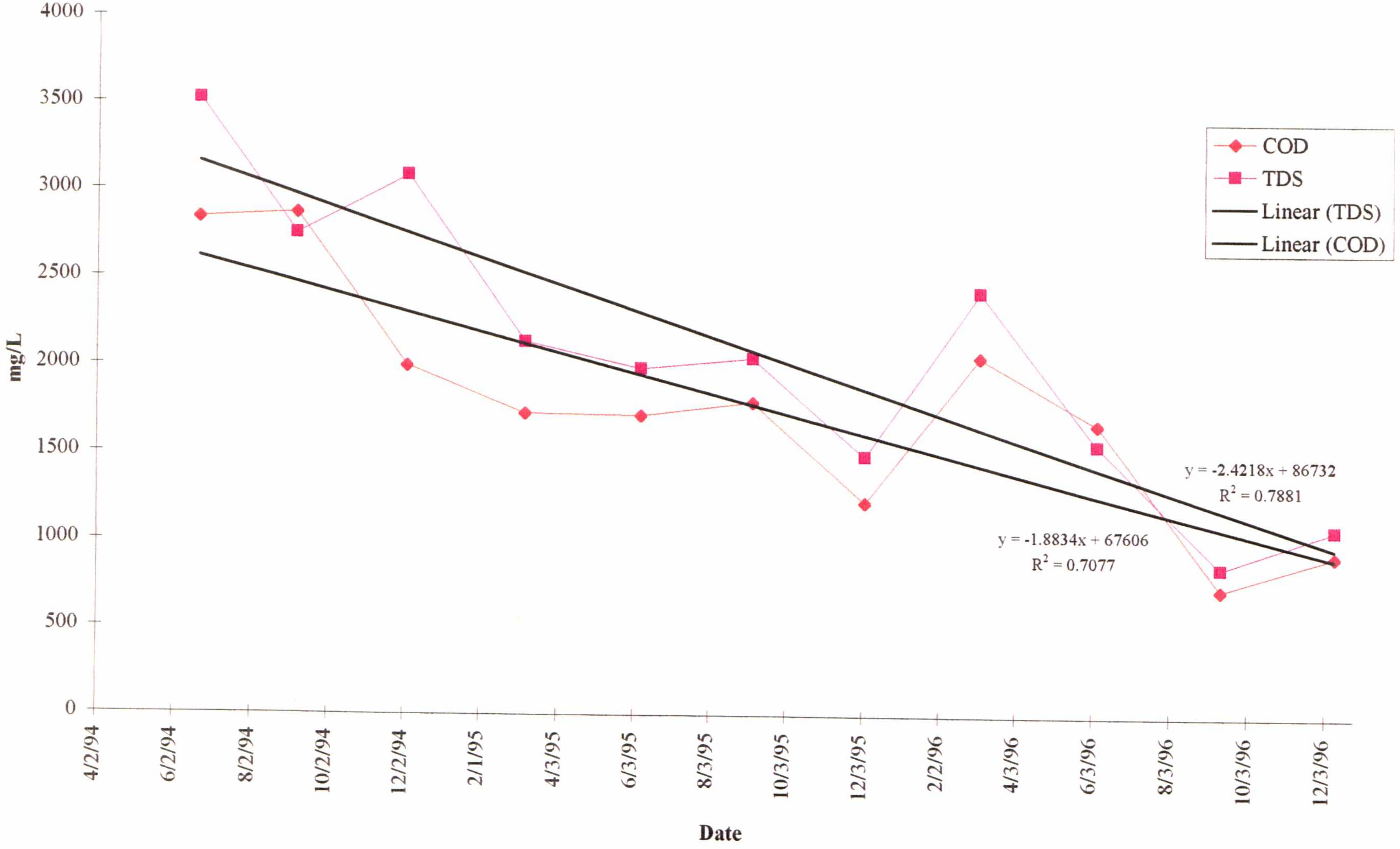


Figure 34B. Temporal Trends in Lagoon Analytical Data
Chloride (Cl) and Oil & Grease (O&G)
(analytes with statistically-significant temporal trends)

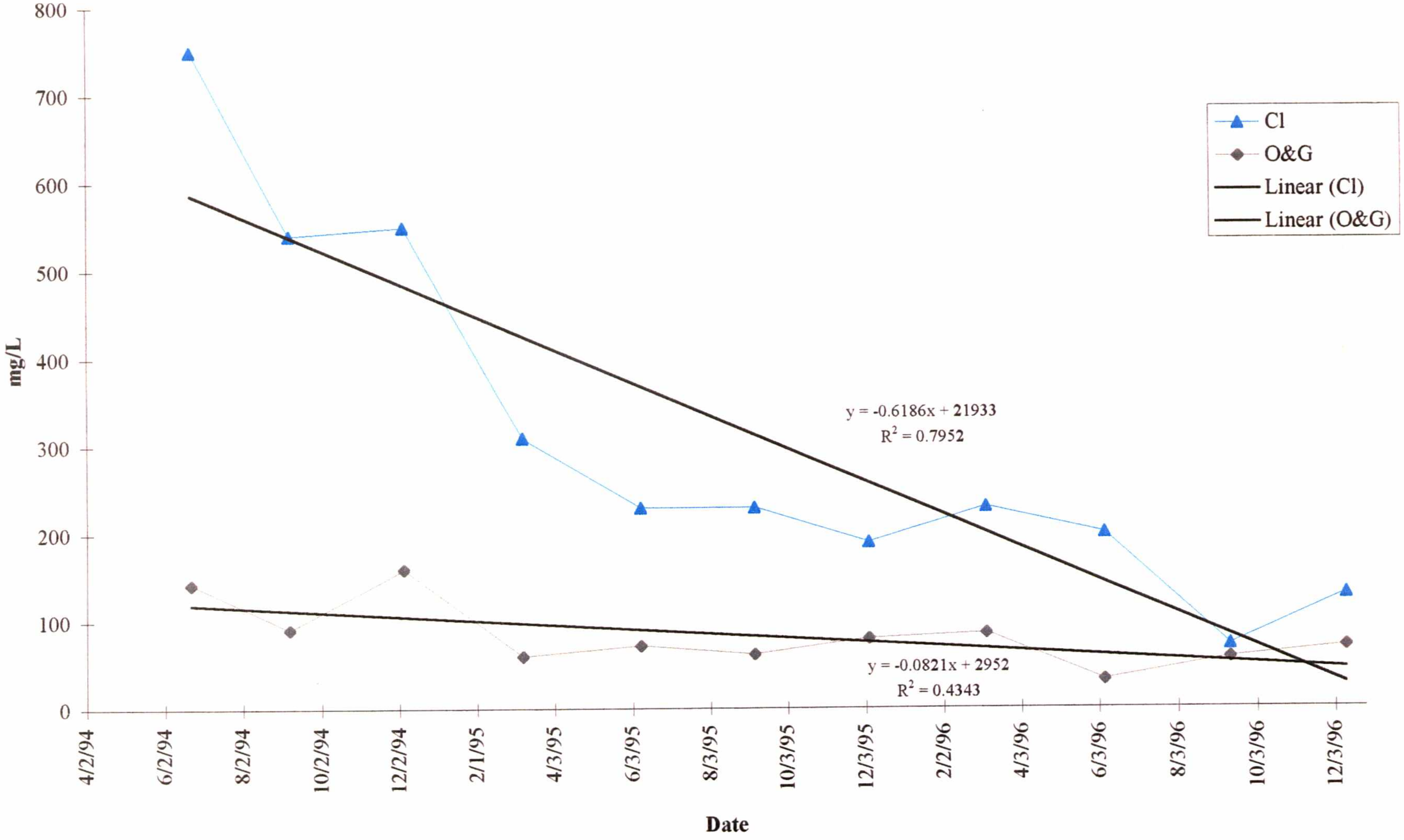


Figure 34C. Temporal Trends in Lagoon Analytical Data -- Total Phenolics (Phenol)
(analytes with statistically-significant temporal trends)

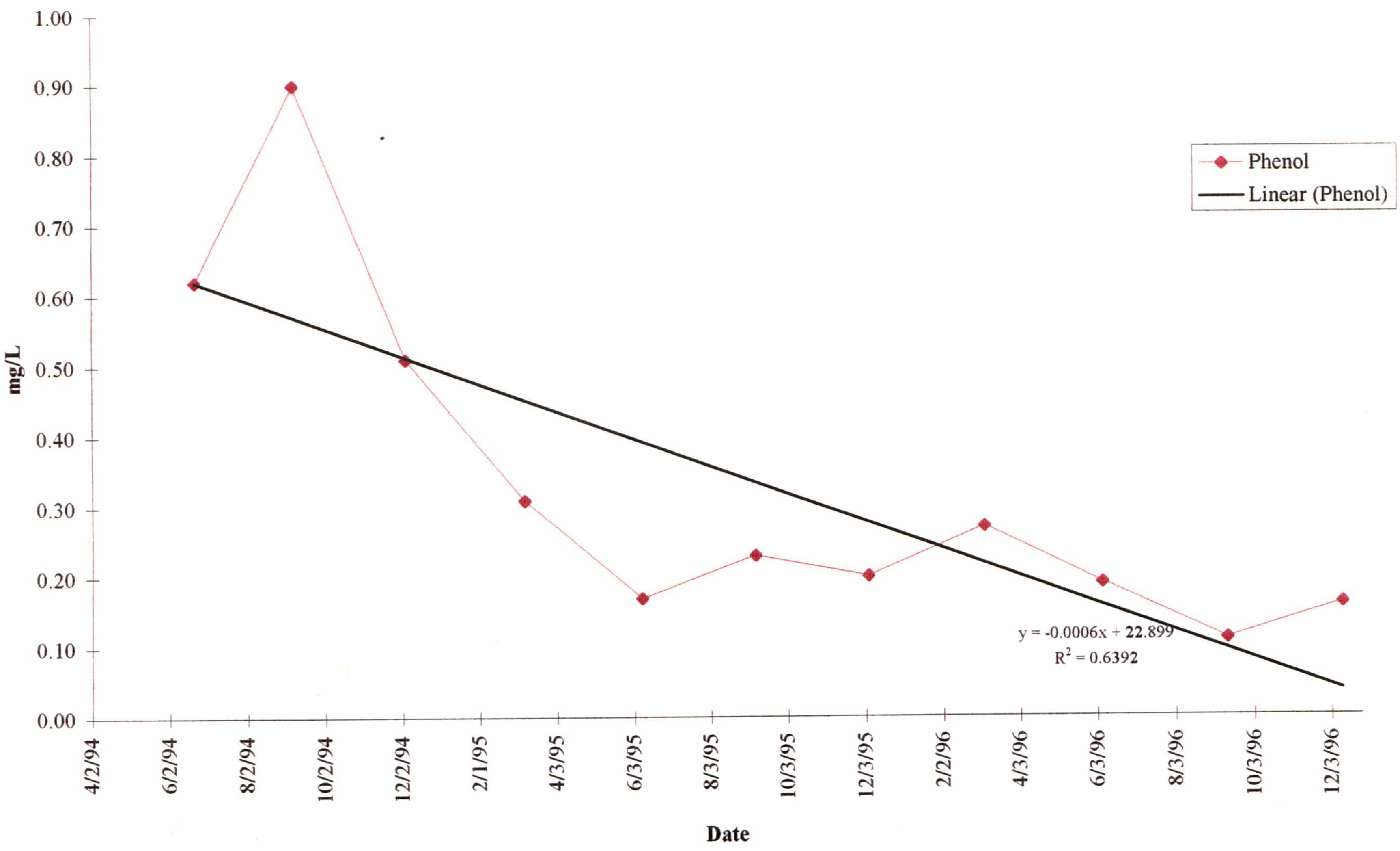


Figure 34D. Temporal Trends in Lagoon Analytical Data -- Tannin & Lignin (T&L)
(analytes with statistically-significant temporal trends)

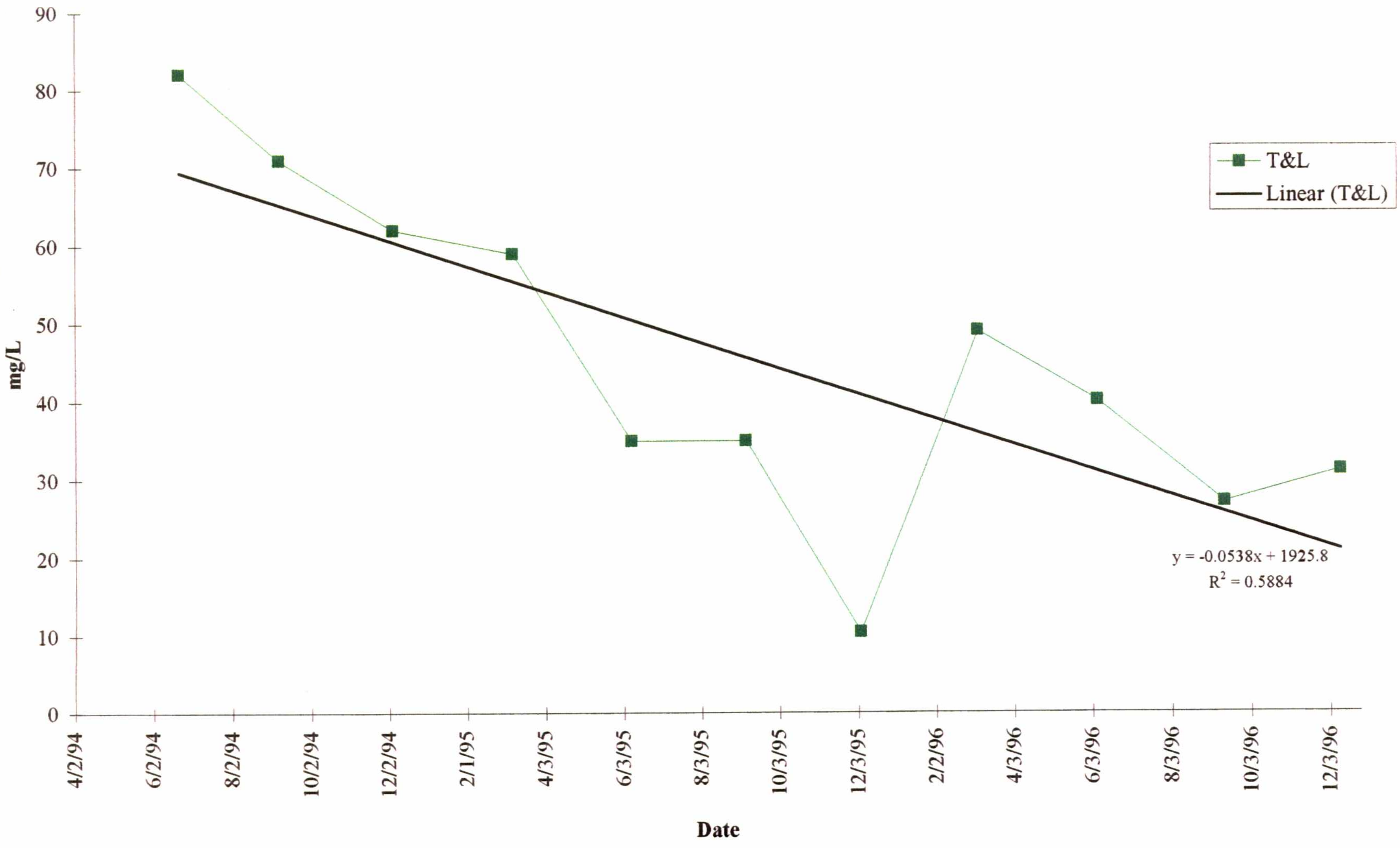
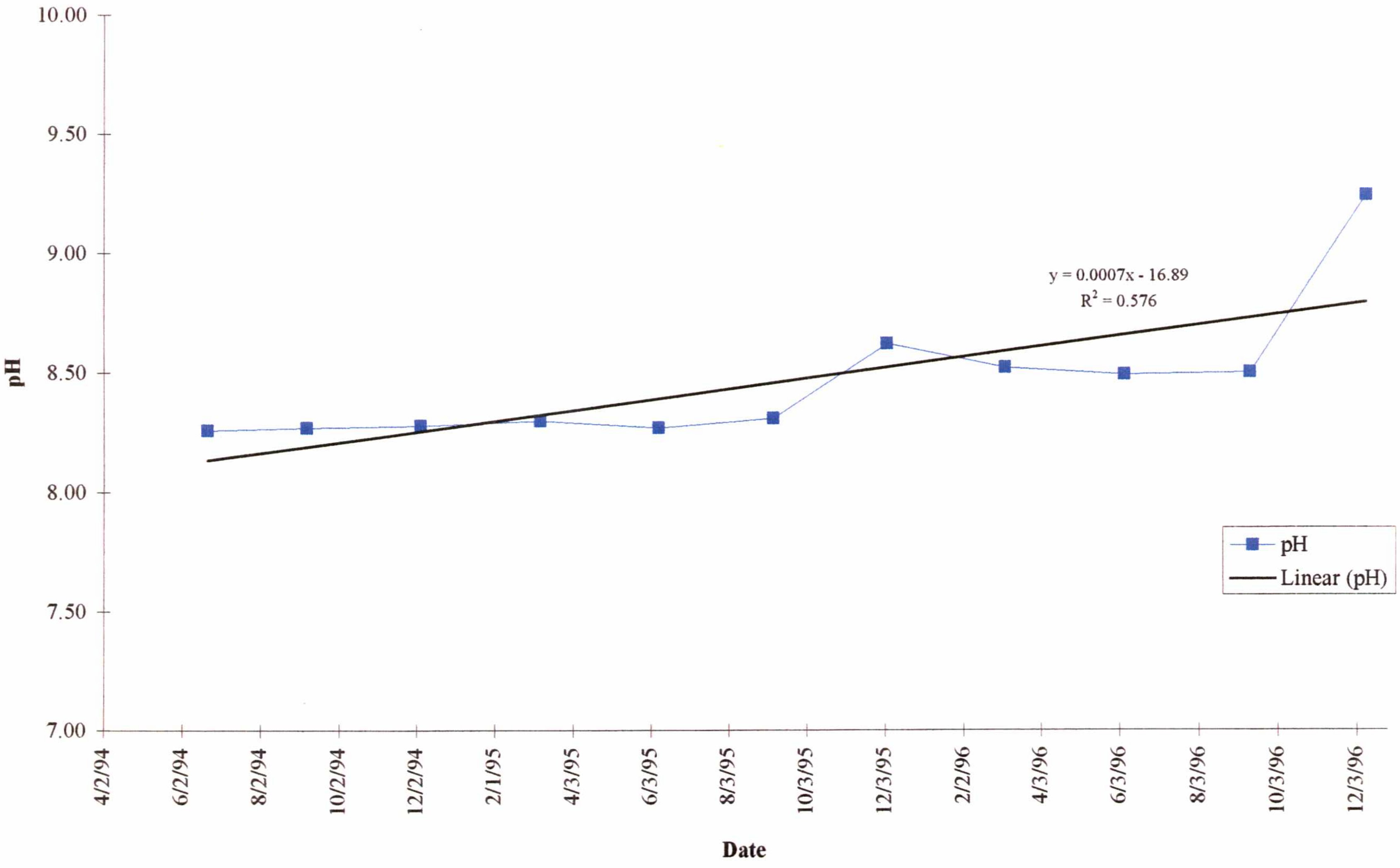


Figure 34E. Temporal Trends in Lagoon Analytical Data -- pH
(analyses with statistically-significant temporal trends)



Photographs

Photo 1. The Process Water Lagoon (looking north). All lagoon samples collected immediately south of the return-flow pump house (the small green building on the east side of the lagoon).

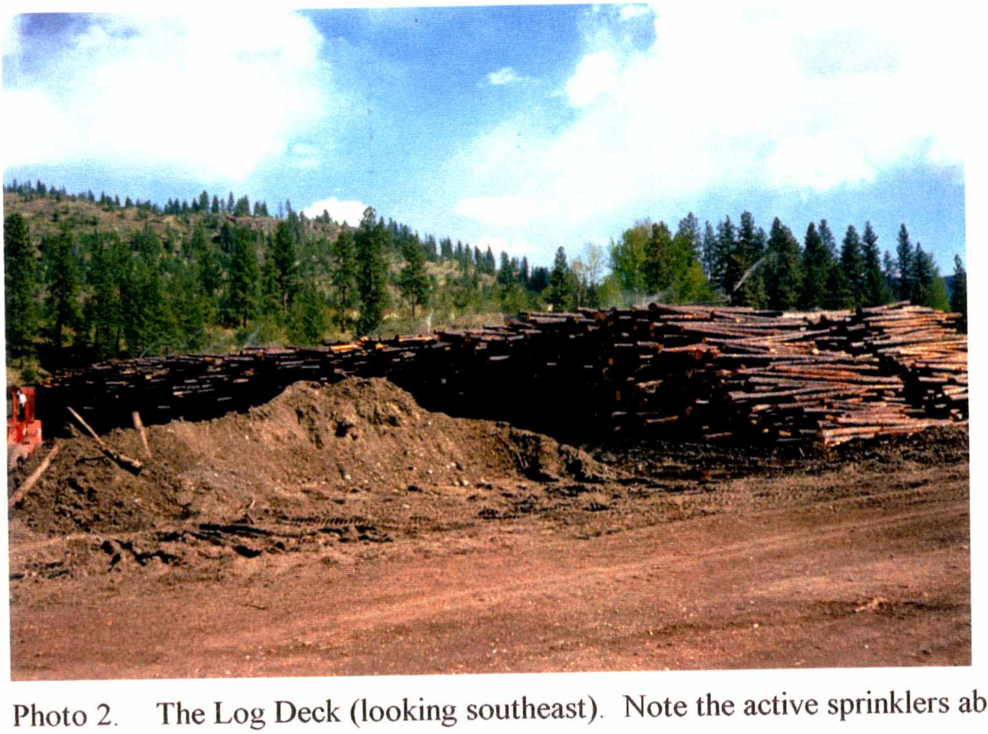


Photo 2. The Log Deck (looking southeast). Note the active sprinklers above the logs.

Photo 3. Wells P-4 and P-4D (looking southwest toward the log deck).

Photo 4. Seep B (looking north-northwest along the Lake Roosevelt shoreline). Note the sample collection pool near the top of the seep and the iron precipitate.

Photo 5. Waterra Groundwater Sampling Pump (in place over well P-3). Well P-3D in foreground.

Photo 6. Grand Coulee Dam with the southern end of Lake Roosevelt impounded behind.

Photo 7. Lake Roosevelt (looking east toward the plywood plant).
Low lake elevation: 368 meters above sea level, May 1997.

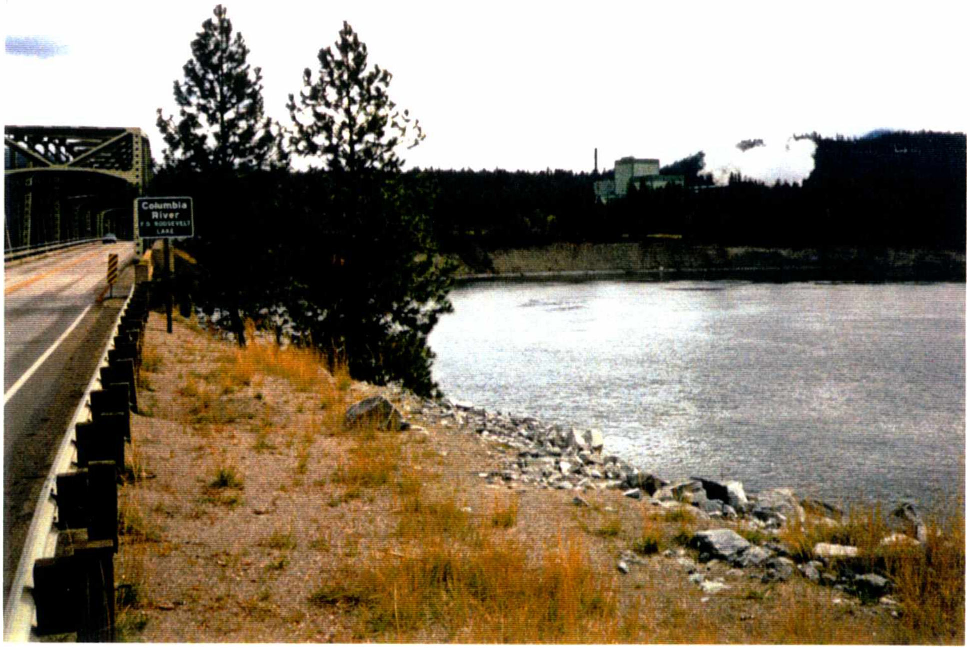


Photo 8. Lake Roosevelt (looking east toward the plywood plant).
High lake elevation: 391 meters above sea level, October 1997.

Photo 9. Lake Roosevelt (looking south-southeast).
Low lake elevation: 368 meters above sea level, May 1997.

Photo 10. Lake Roosevelt (looking south-southeast).
High lake elevation: 391 meters above sea level, October 1997.

Photo 11. Lake Roosevelt (looking north-northeast toward the slightly exposed Kettle Falls). Low lake elevation: 368 meters above sea level, May 1997.

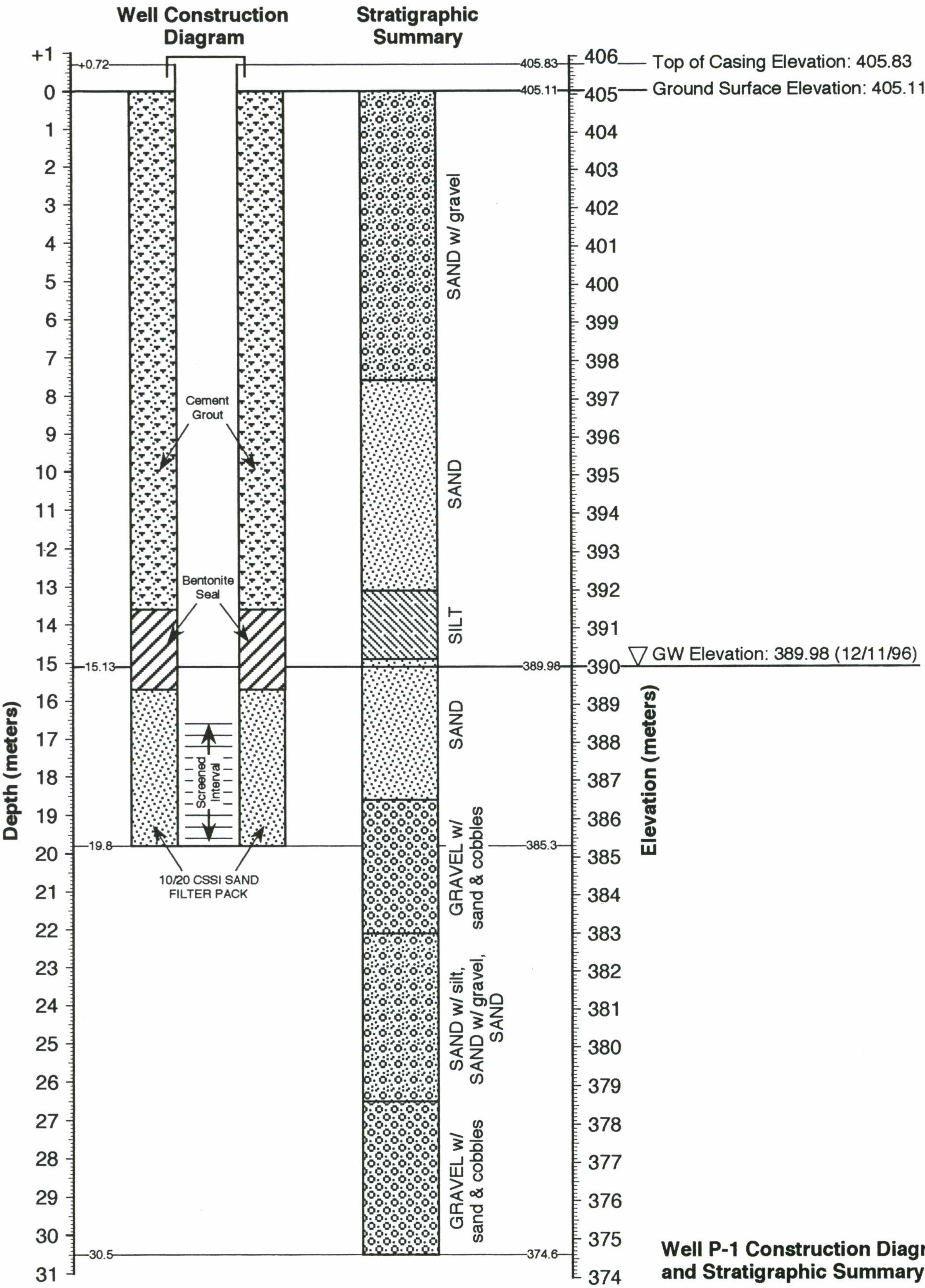
Photo 12. Lake Roosevelt (looking north-northeast toward the submerged Kettle Falls). High lake elevation: 391 meters above sea level, October 1997.

Appendices

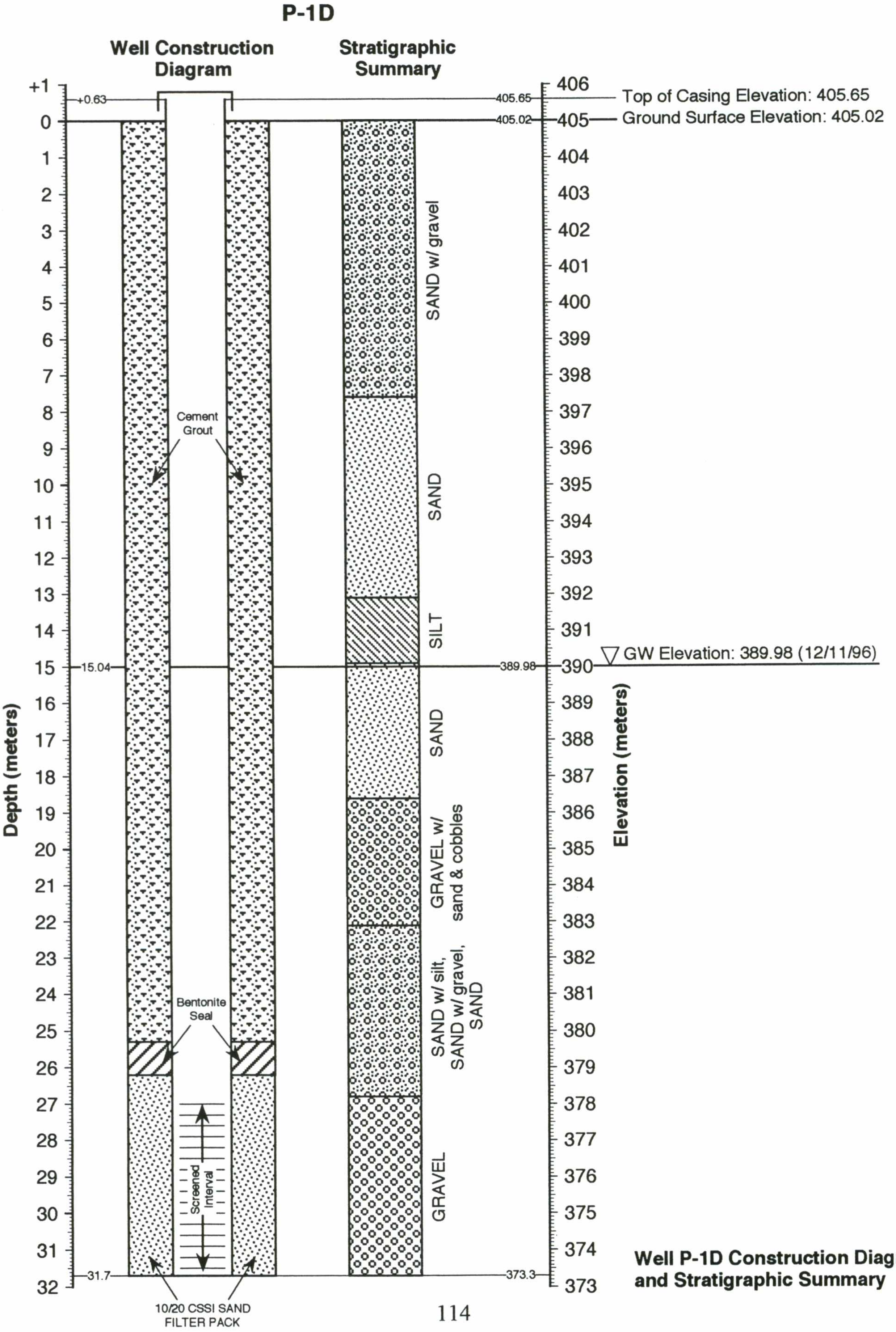
APPENDIX C. CHEMICAL DISTRIBUTION CONTOUR MAPS

APPENDIX A. WELL CONSTRUCTION / STRATIGRAPHIC SUMMARIES

P-1

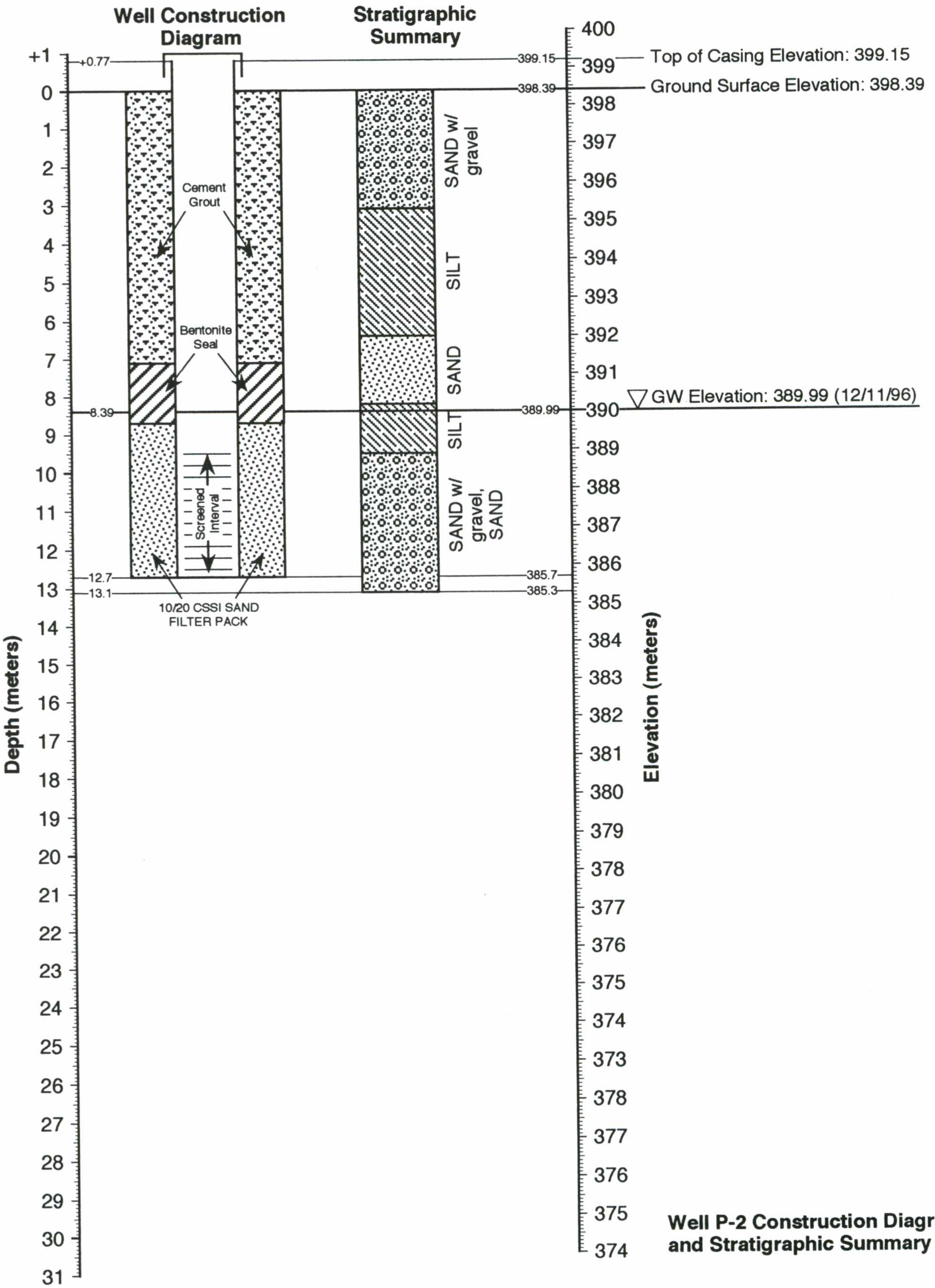


Well P-1 Construction Diagram and Stratigraphic Summary

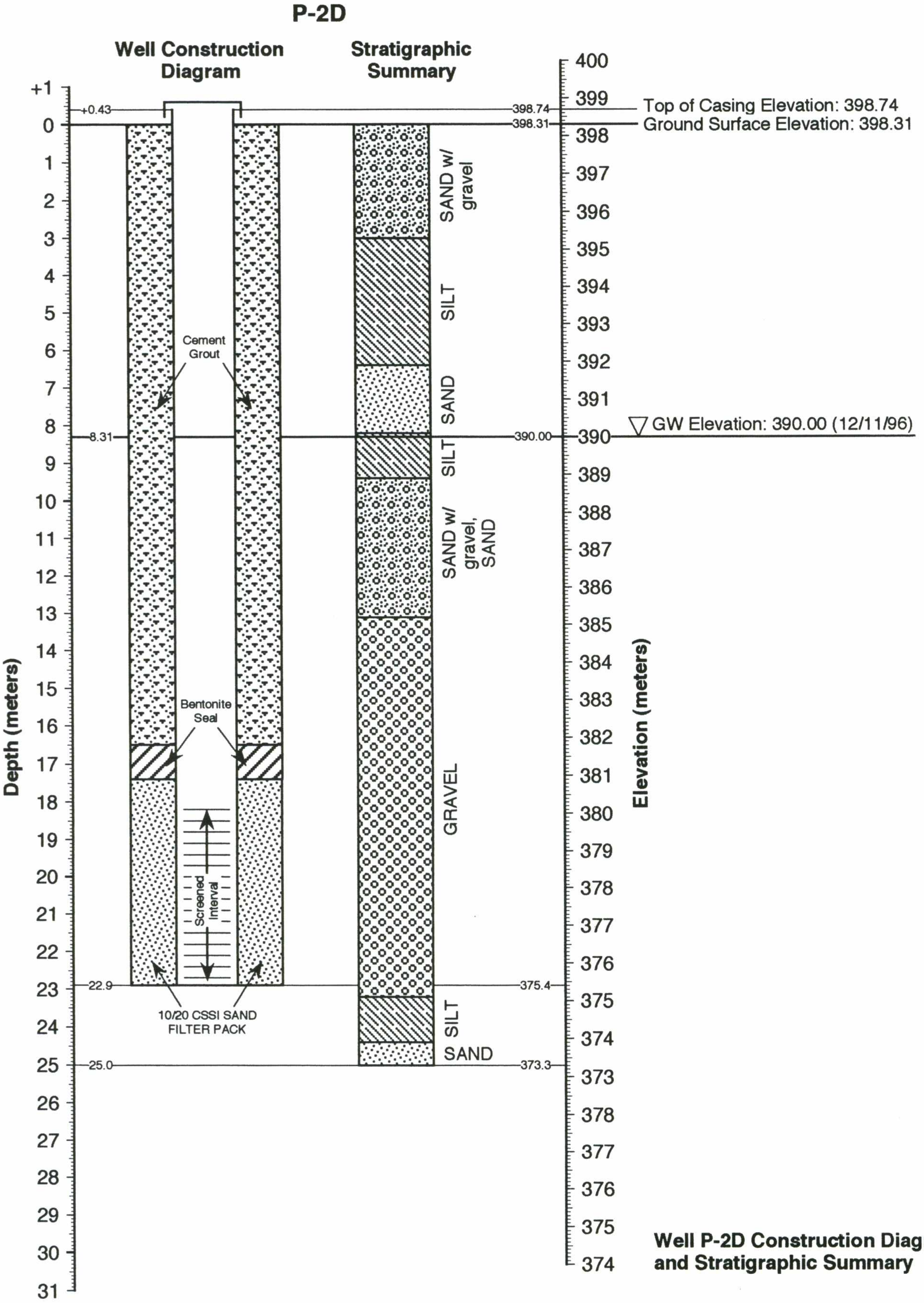


Well P-1D Construction Diagram and Stratigraphic Summary

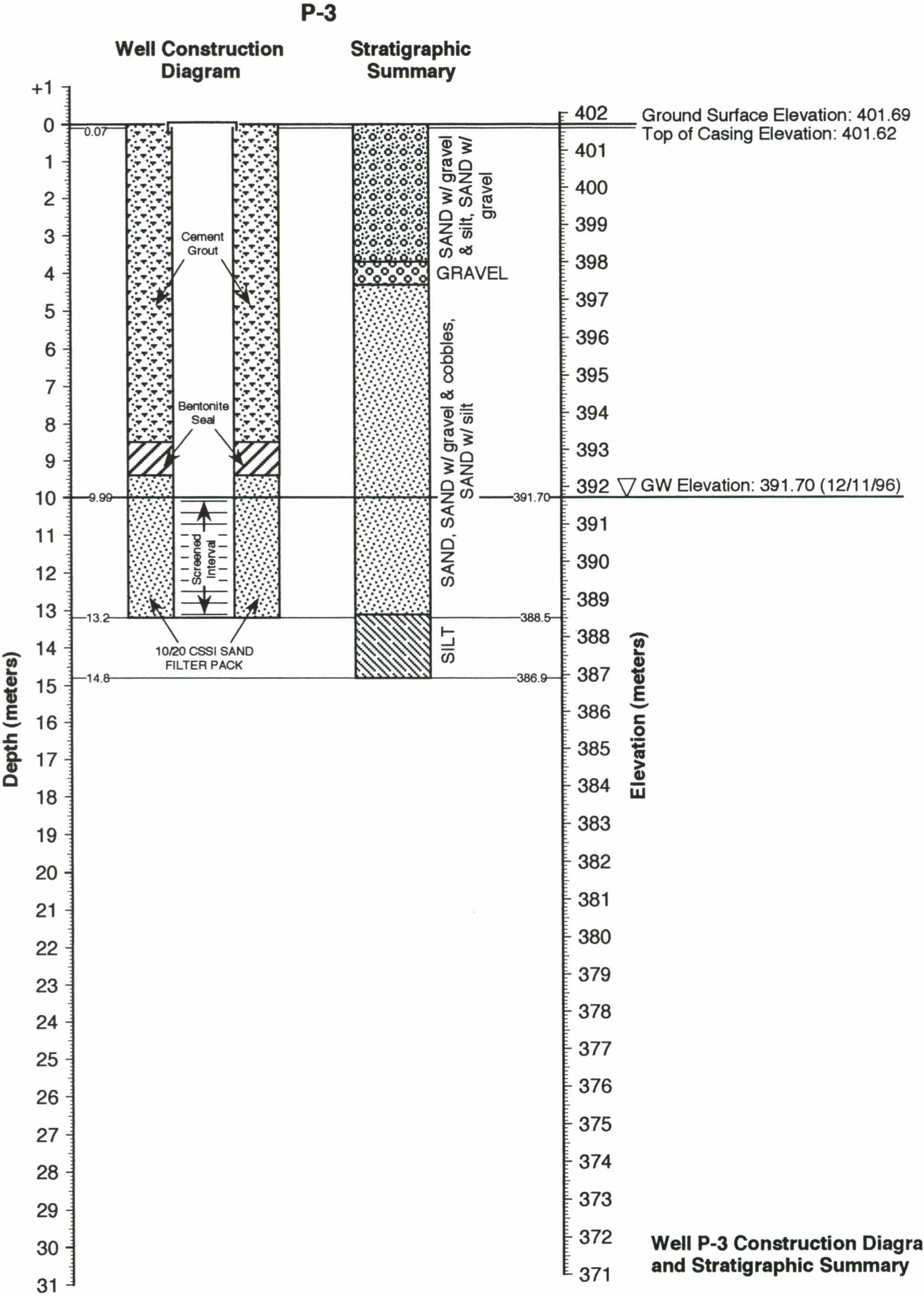
P-2



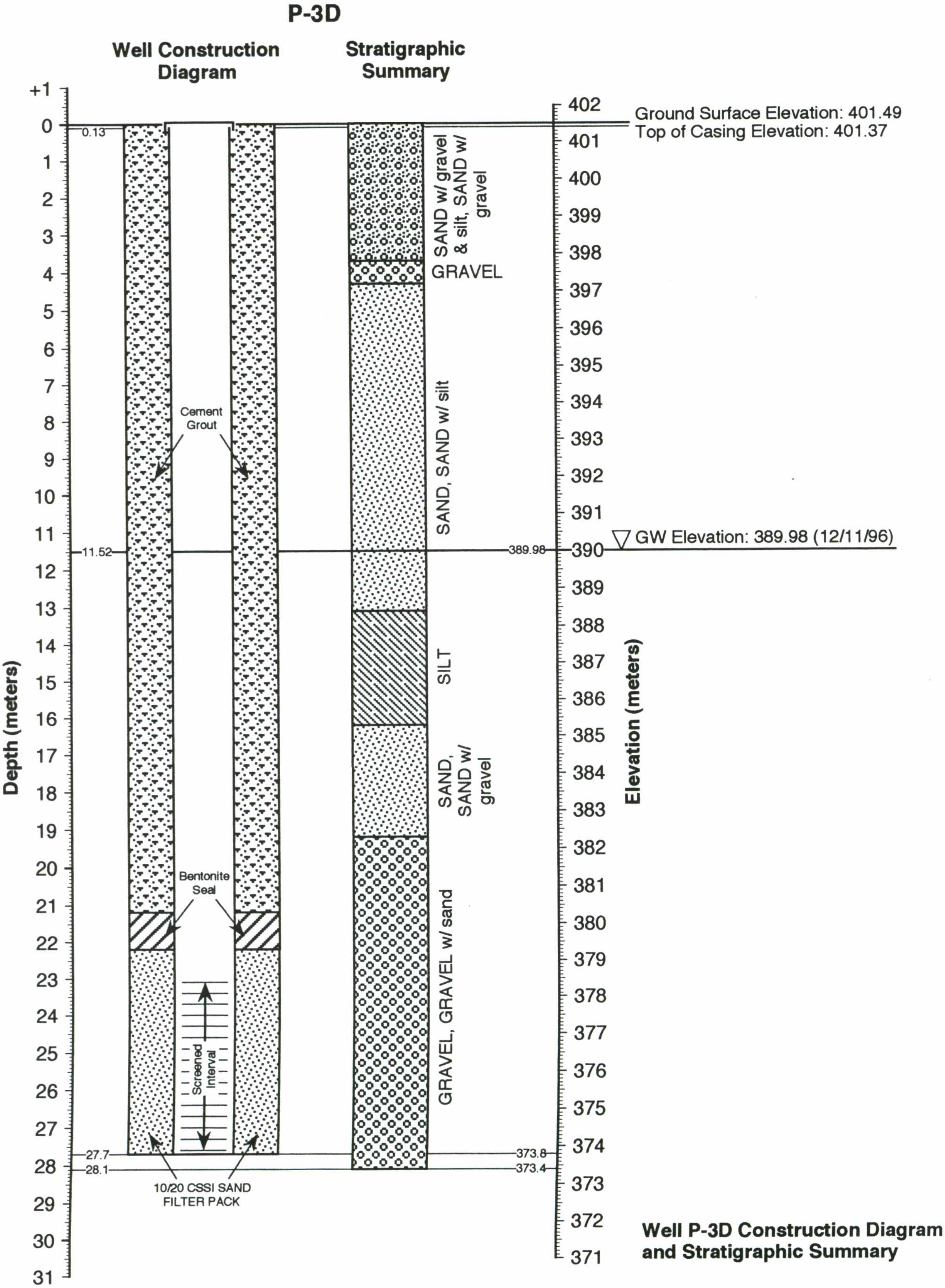
Well P-2 Construction Diagram and Stratigraphic Summary



Well P-2D Construction Diagram and Stratigraphic Summary

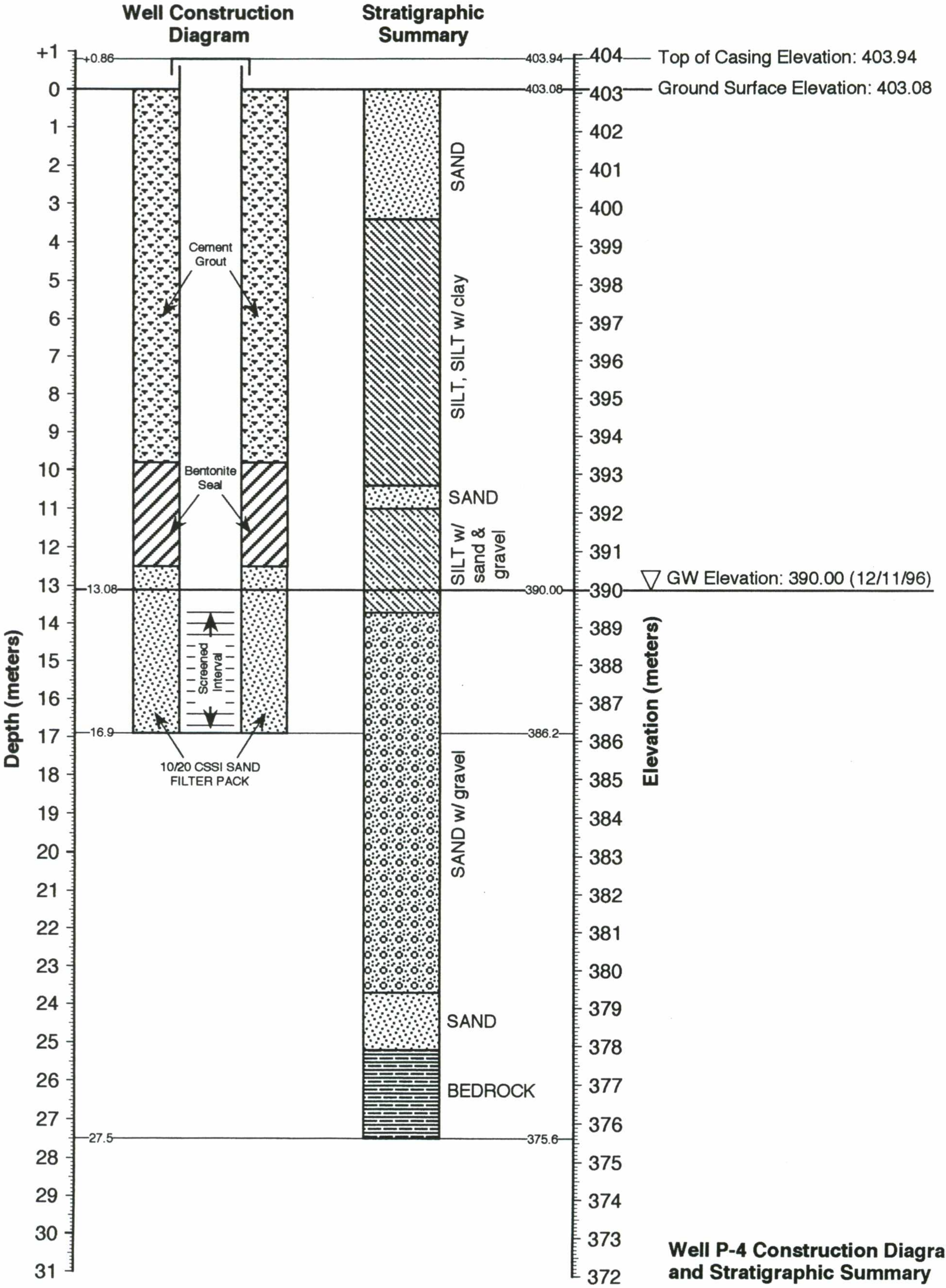


Well P-3 Construction Diagram and Stratigraphic Summary

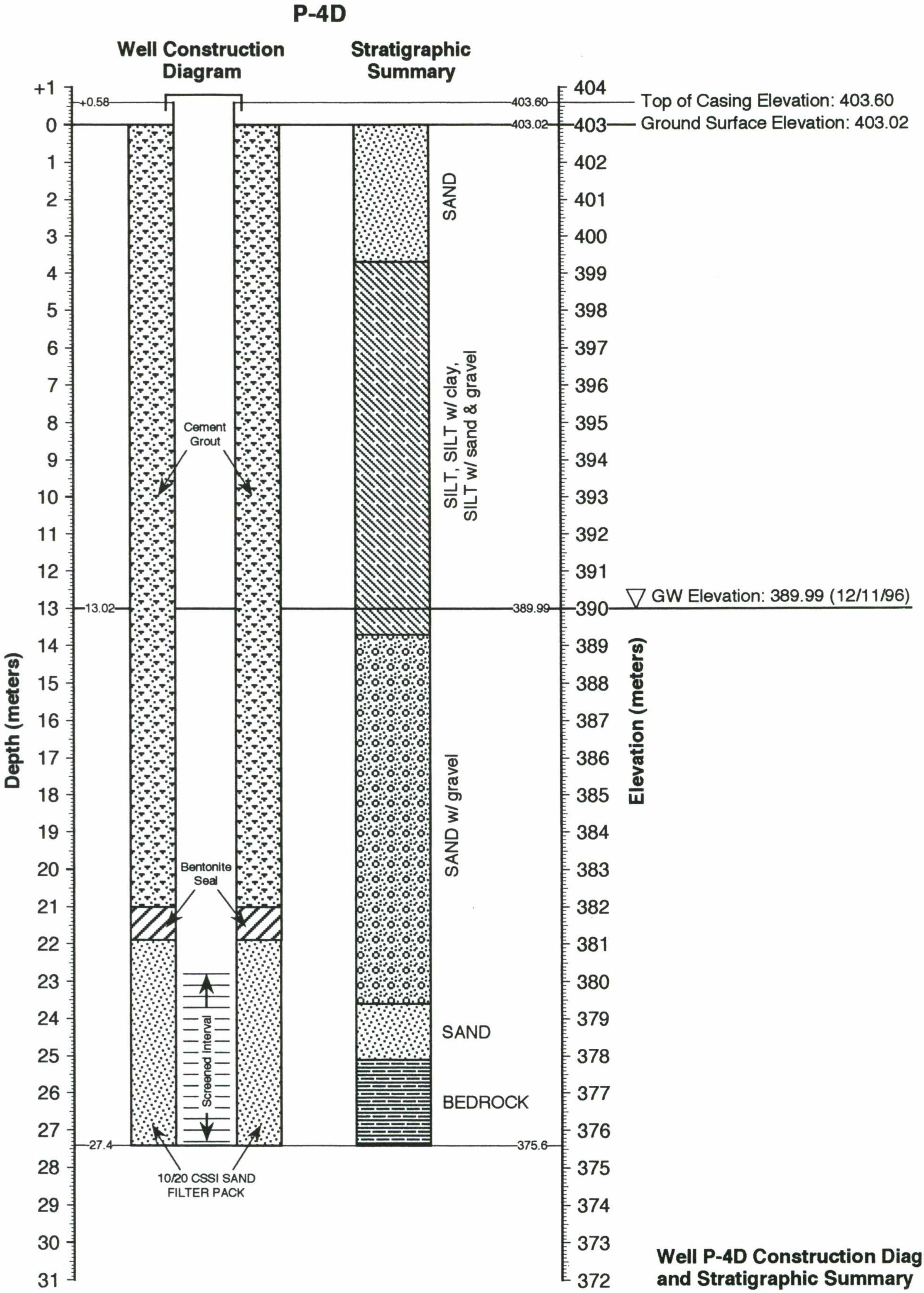


Well P-3D Construction Diagram and Stratigraphic Summary

P-4

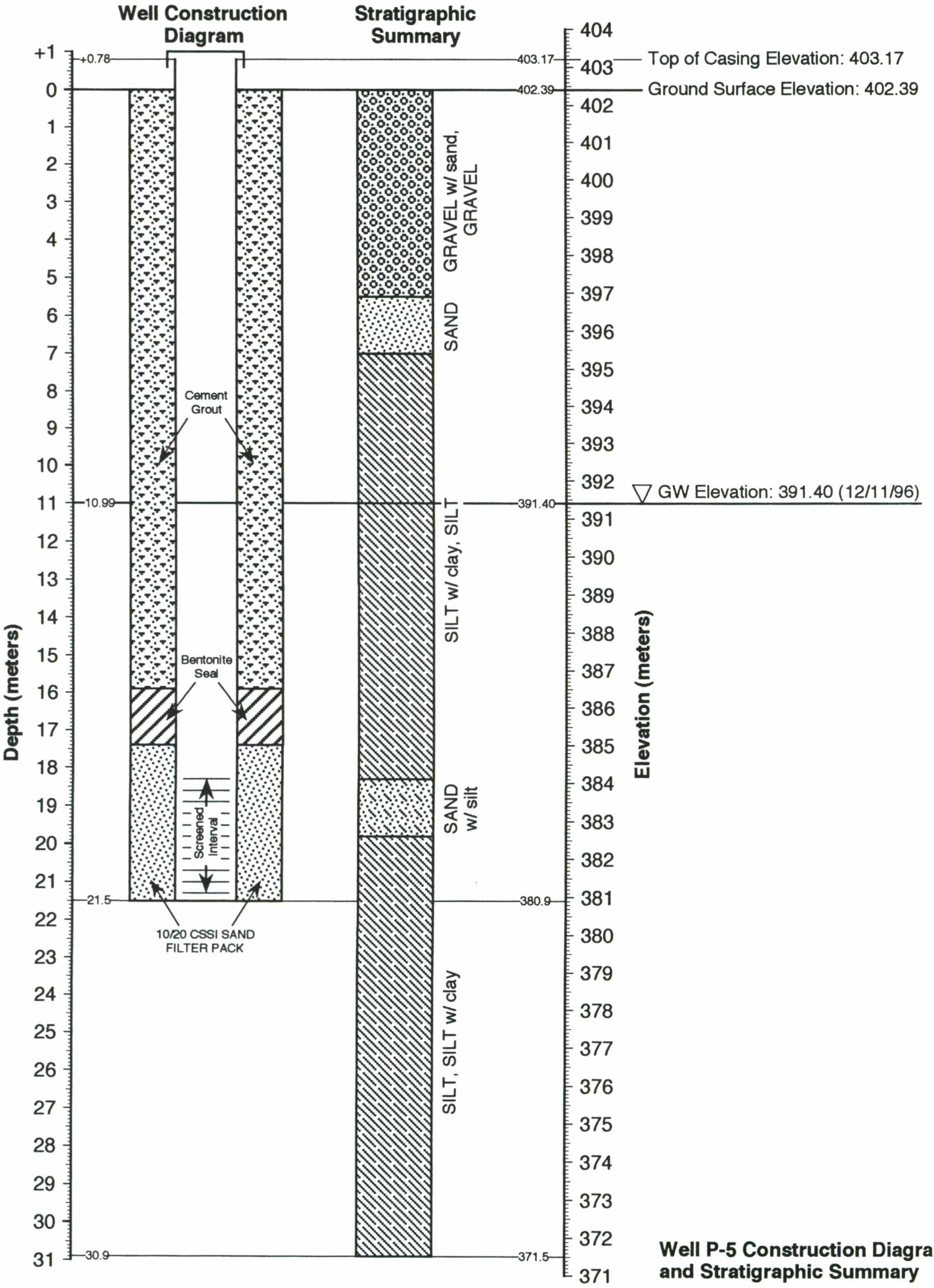


Well P-4 Construction Diagram and Stratigraphic Summary



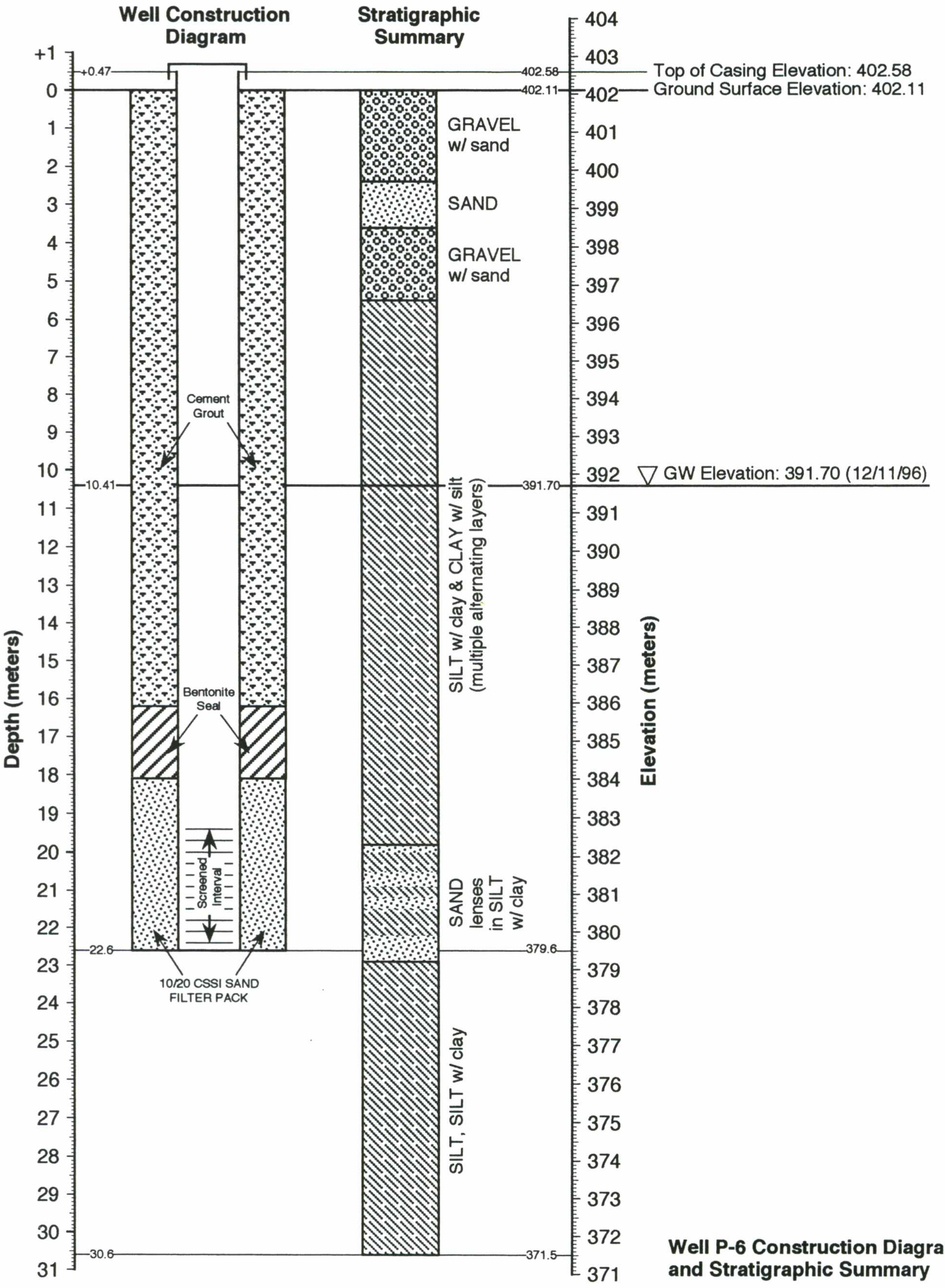
Well P-4D Construction Diagram and Stratigraphic Summary

P-5



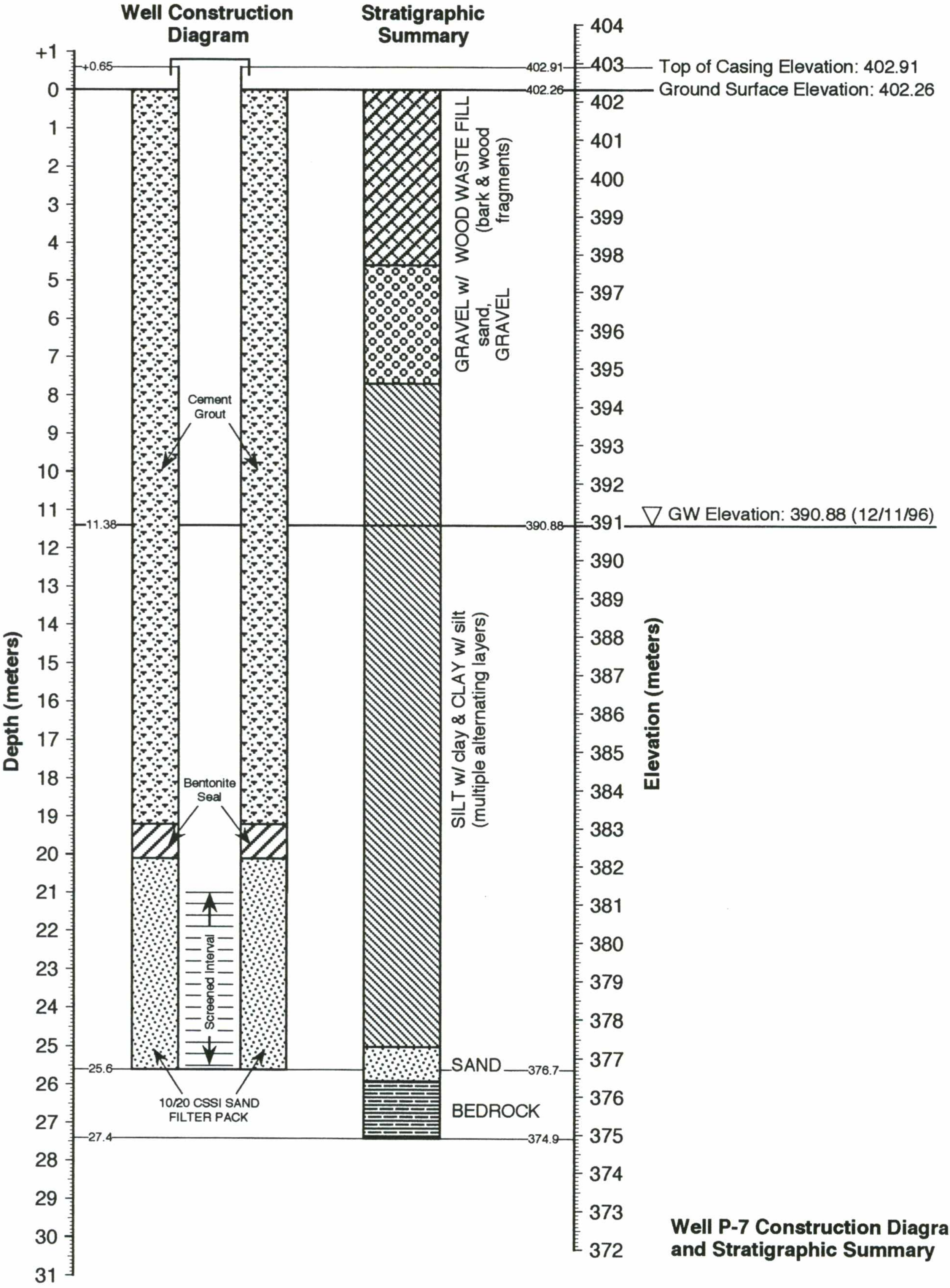
Well P-5 Construction Diagram and Stratigraphic Summary

P-6



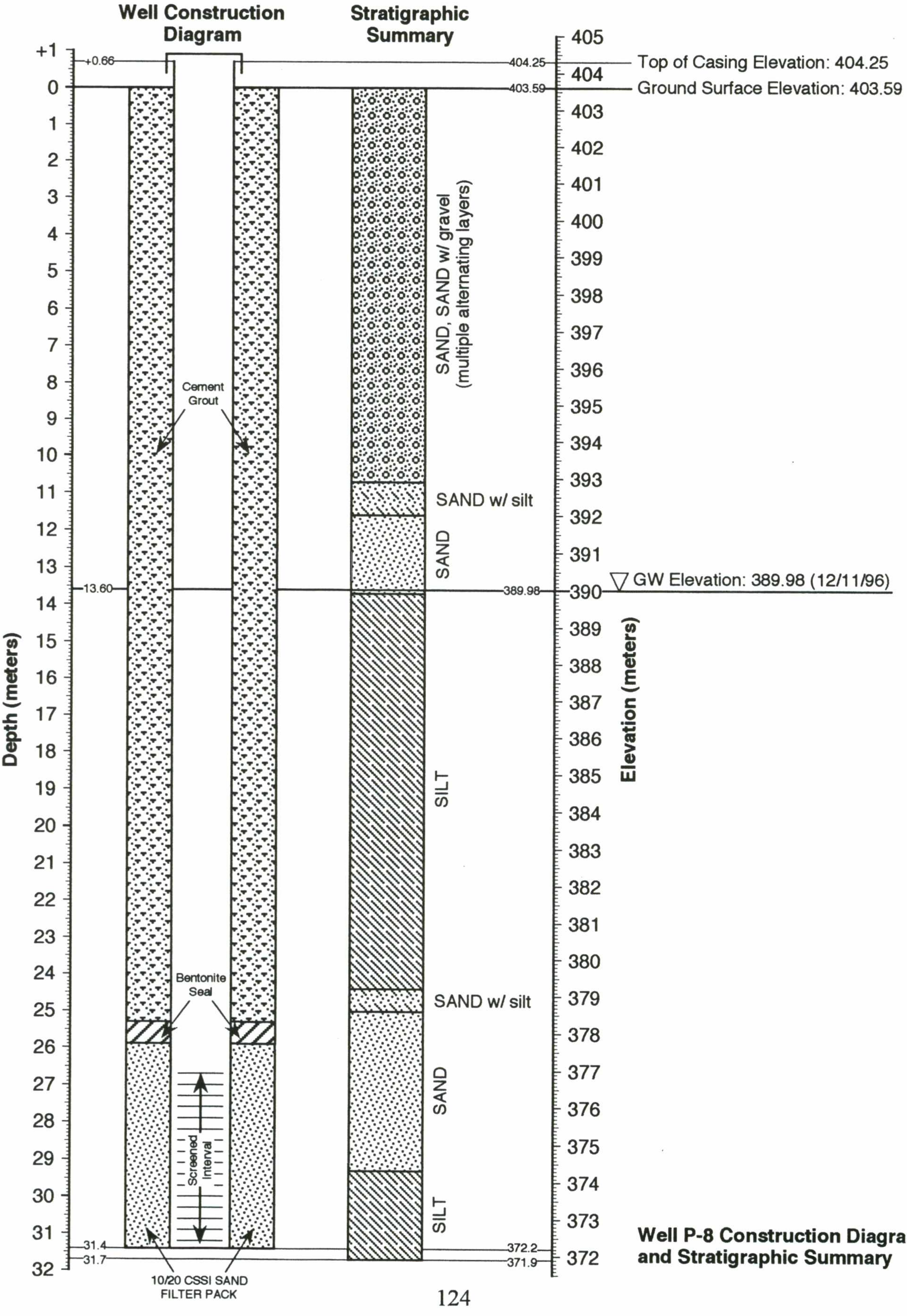
Well P-6 Construction Diagram and Stratigraphic Summary

P-7



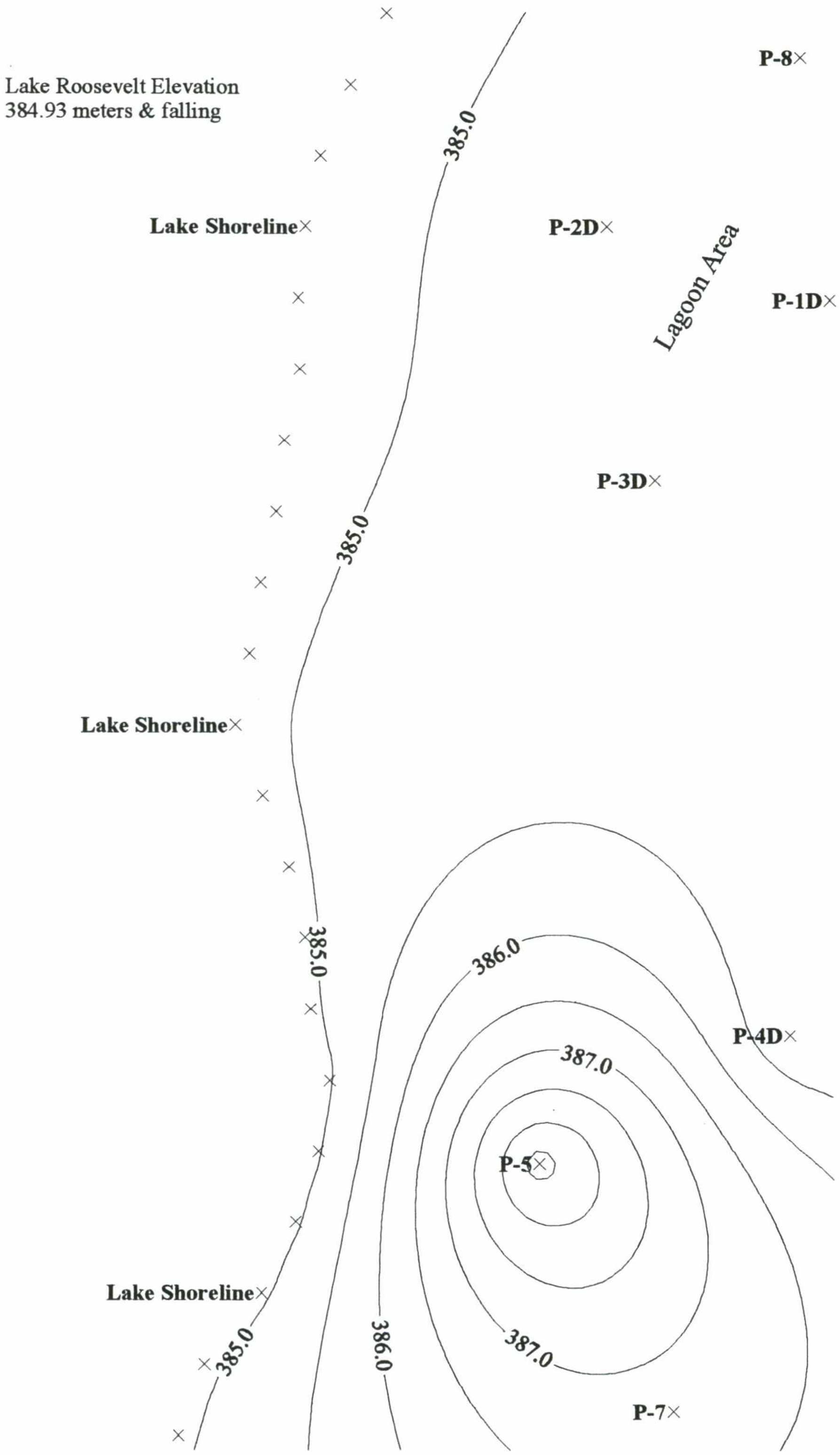
Well P-7 Construction Diagram and Stratigraphic Summary

P-8



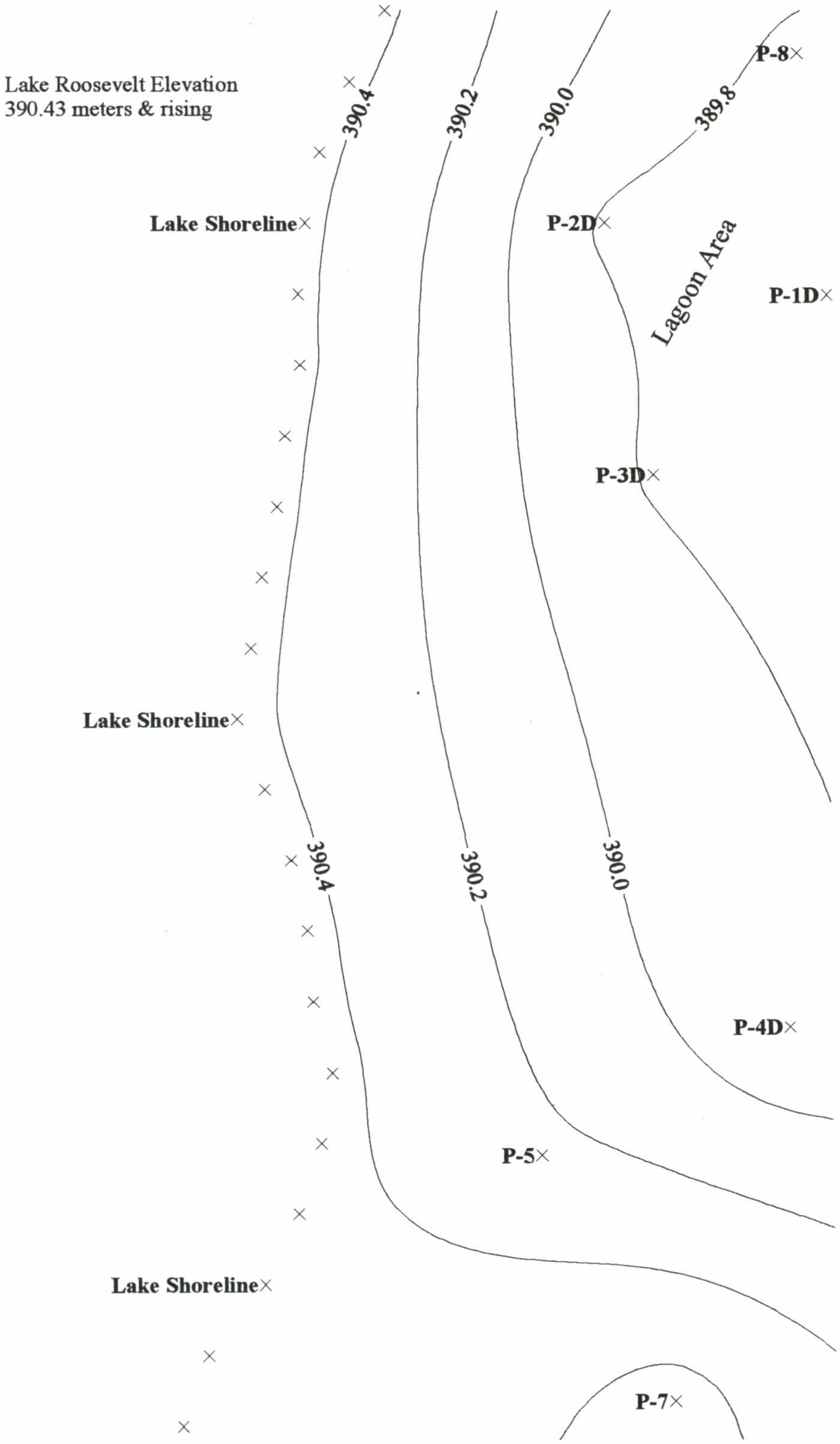
Well P-8 Construction Diagram and Stratigraphic Summary

APPENDIX B. GROUNDWATER ELEVATION CONTOUR MAPS



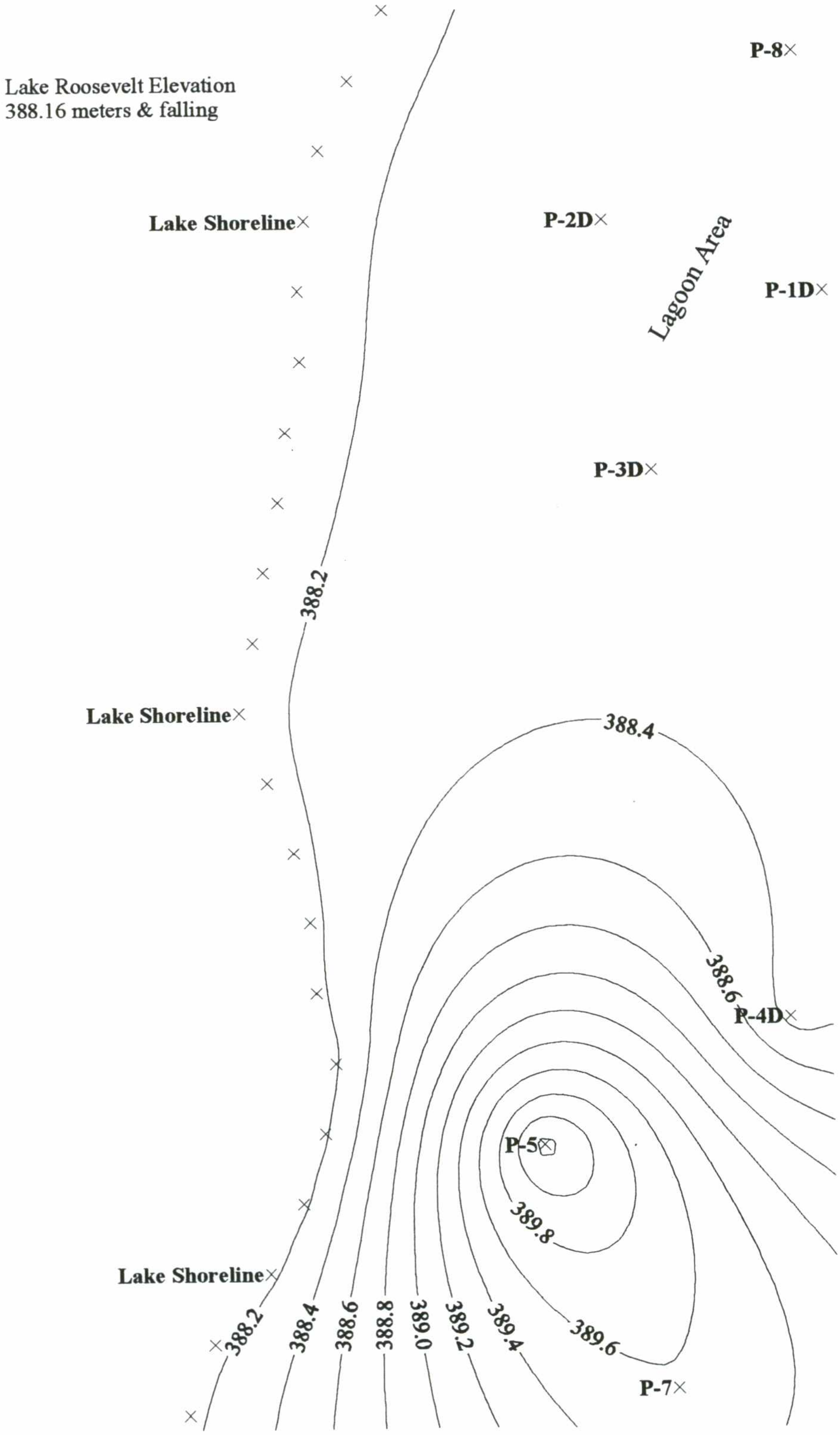
Groundwater Elevation Contour Map - 4/19/94

Contour Interval = 0.5 meters



Groundwater Elevation Contour Map - 5/17/94

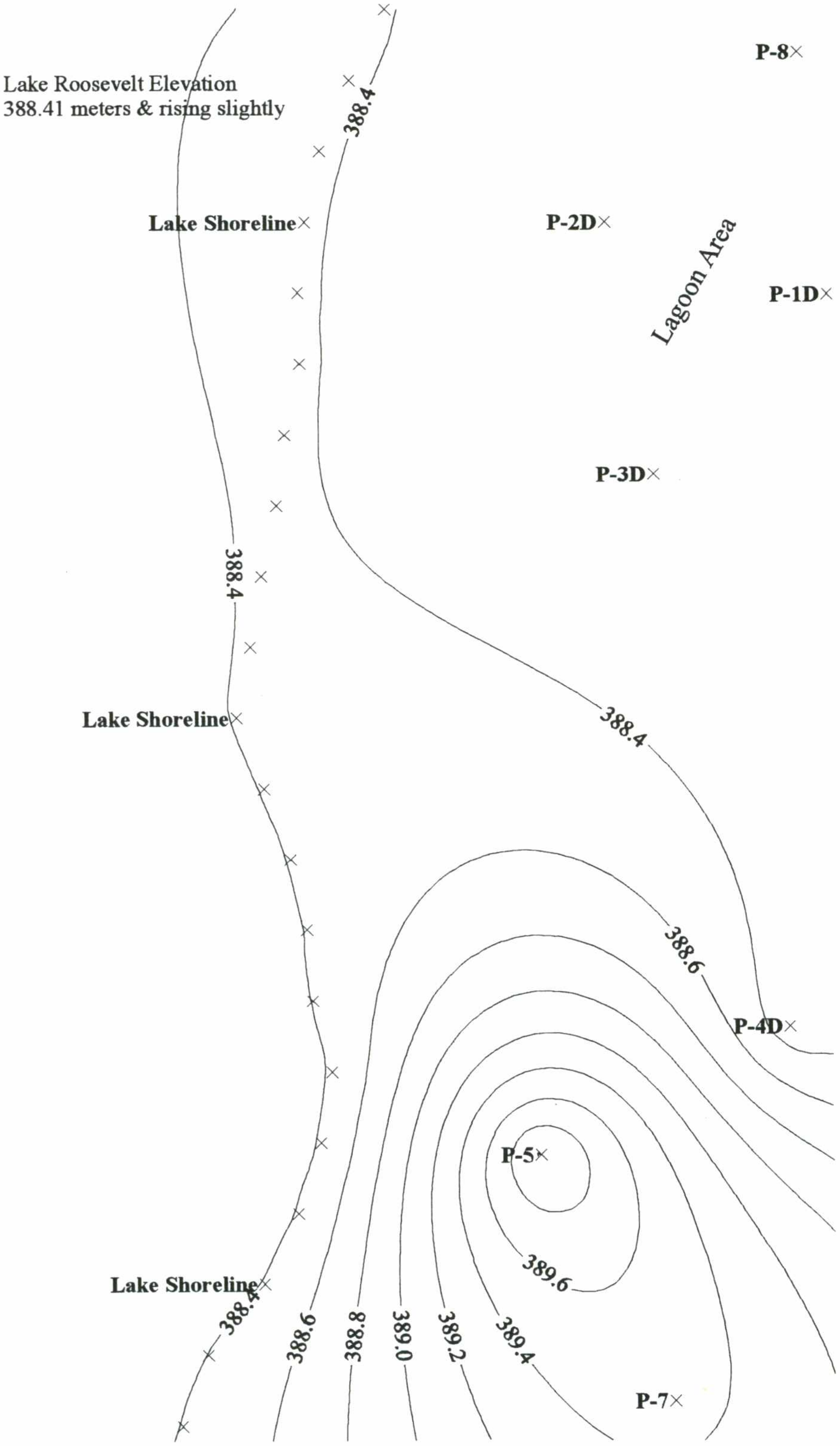
Contour Interval = 0.2 meters



Lake Roosevelt Elevation
388.16 meters & falling

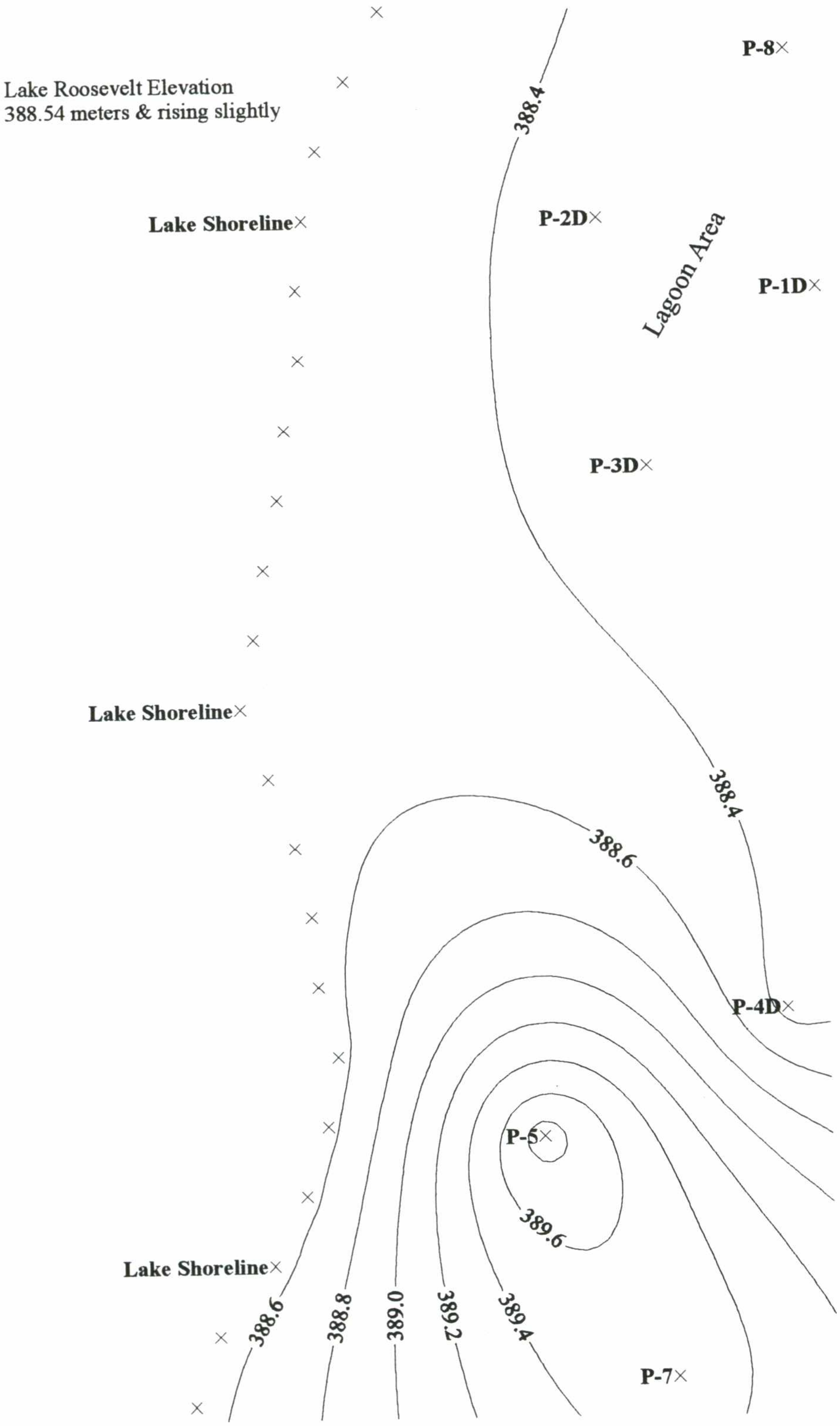
Groundwater Elevation Contour Map - 6/21/94

Contour Interval = 0.2 meters

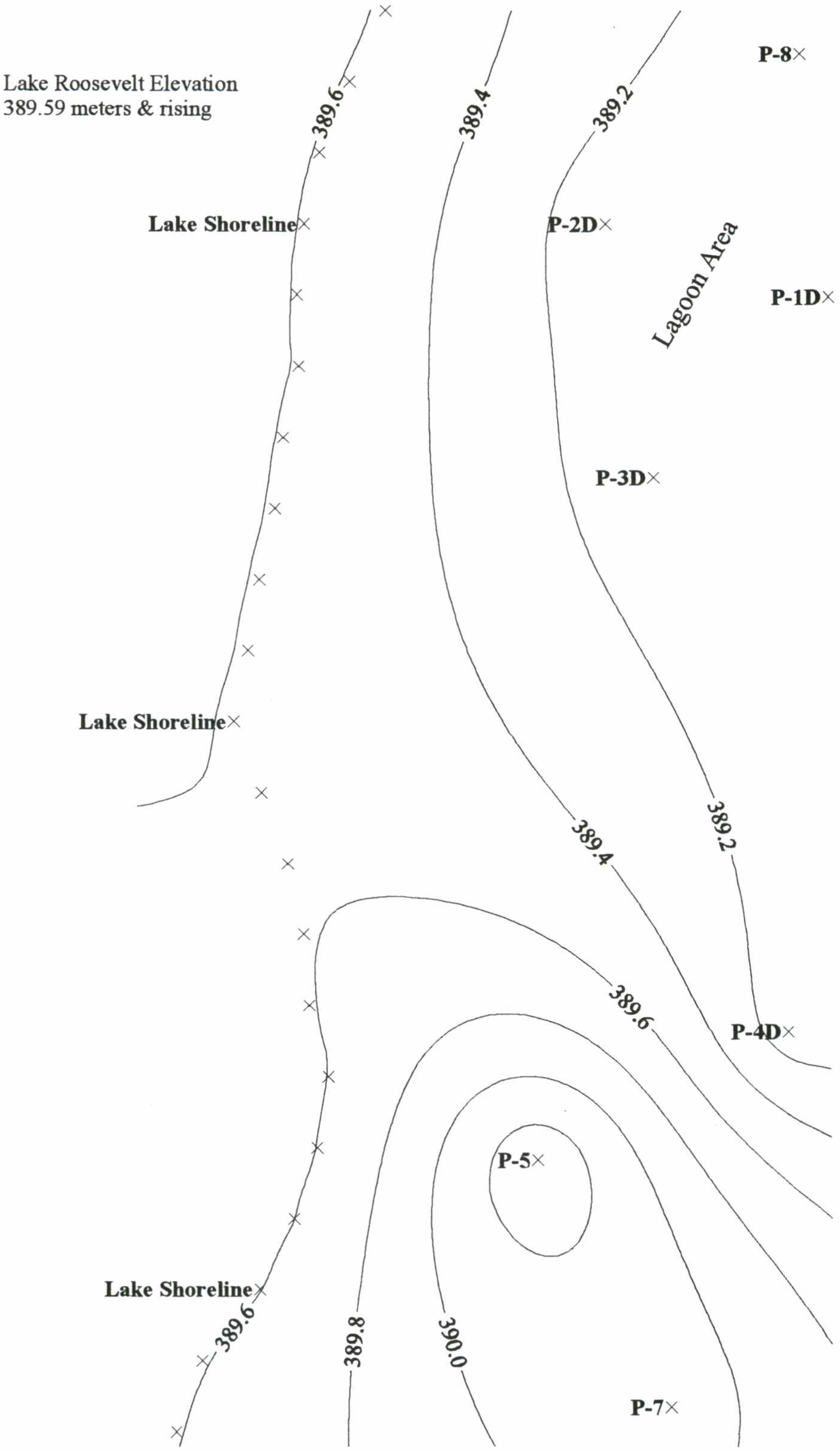


Groundwater Elevation Contour Map - 7/18/94

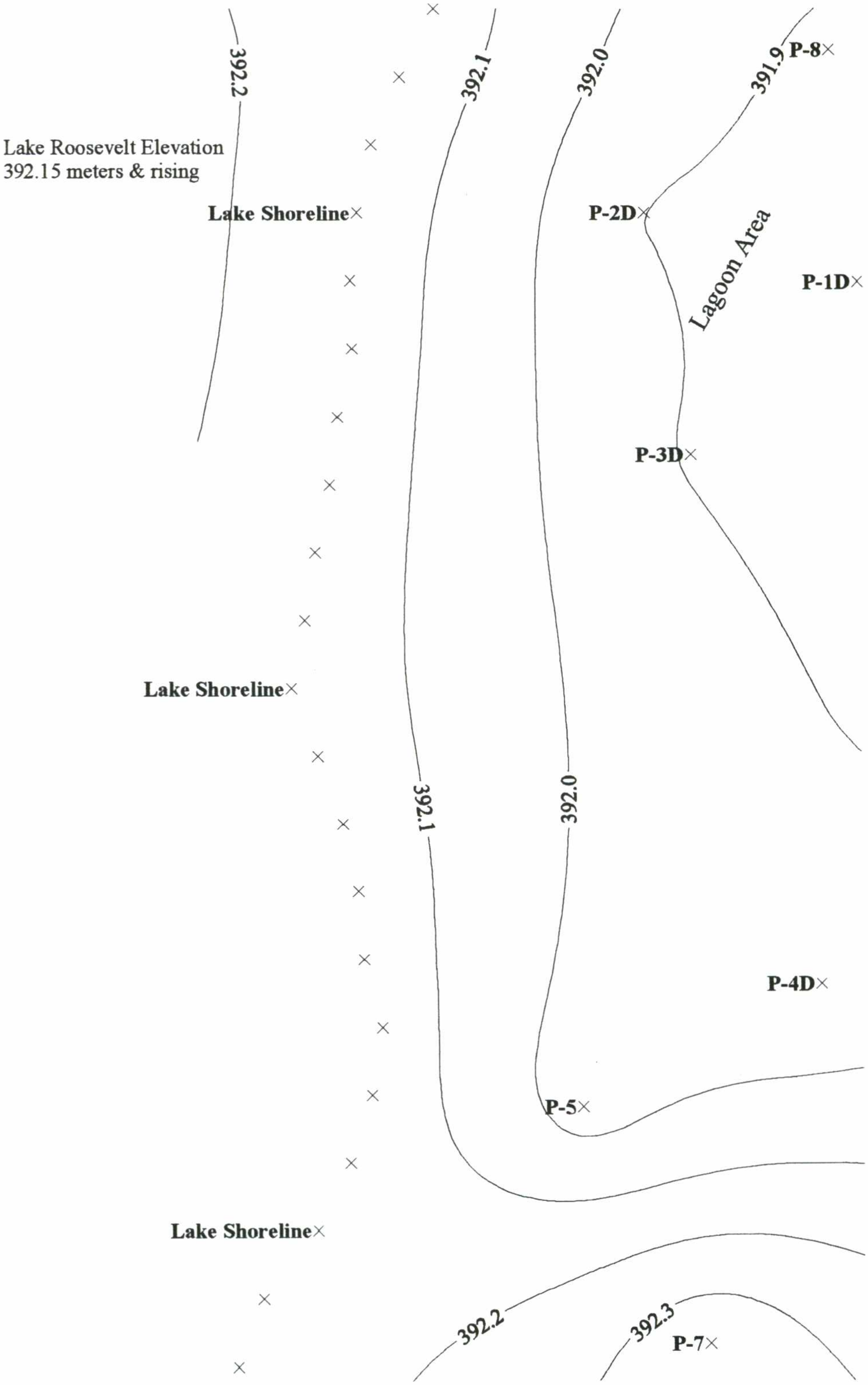
Contour Interval = 0.2 meters



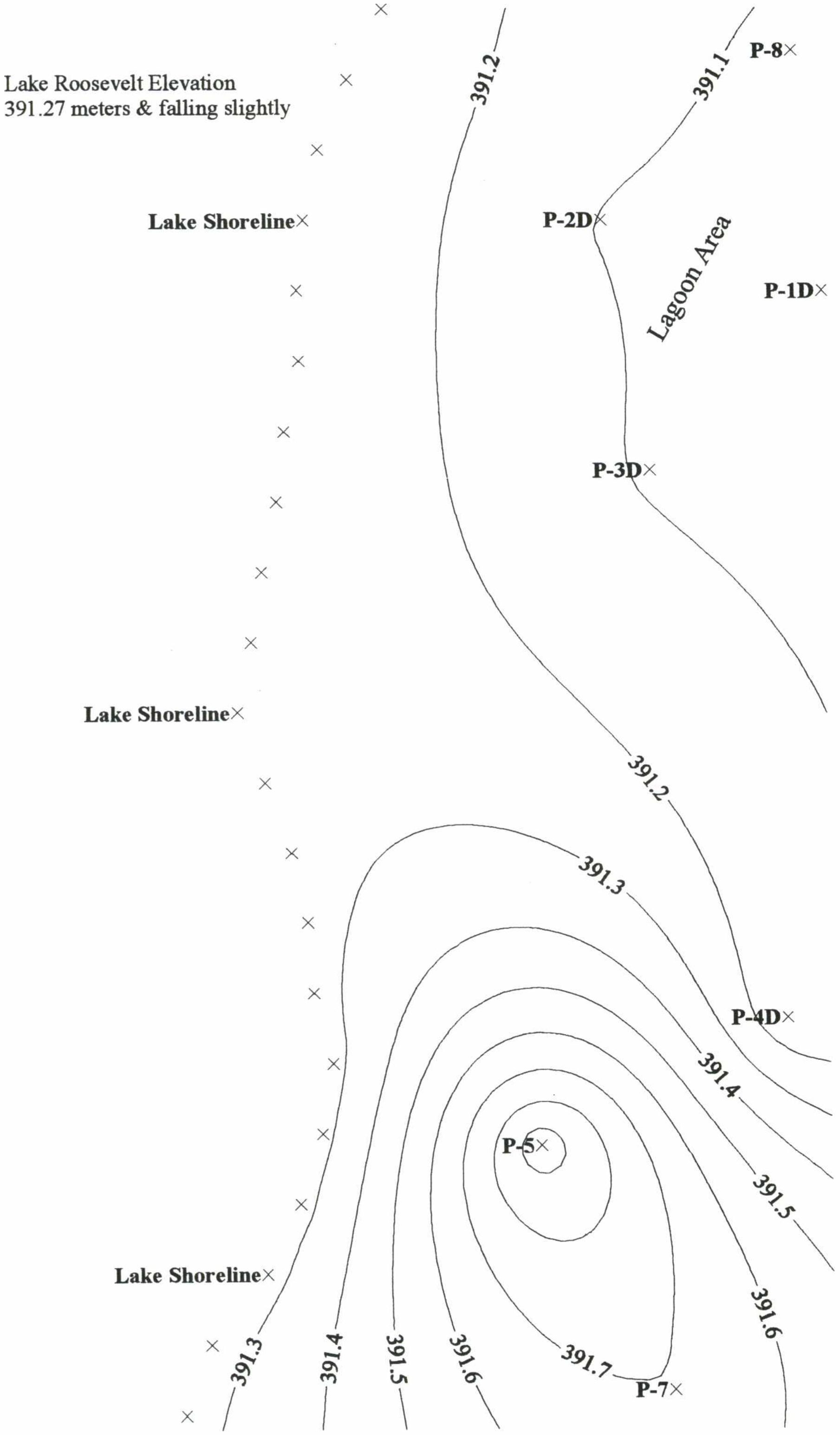
Groundwater Elevation Contour Map - 8/10/94
Contour Interval = 0.2 meters



Groundwater Elevation Contour Map - 9/6/94
Contour Interval = 0.2 meters

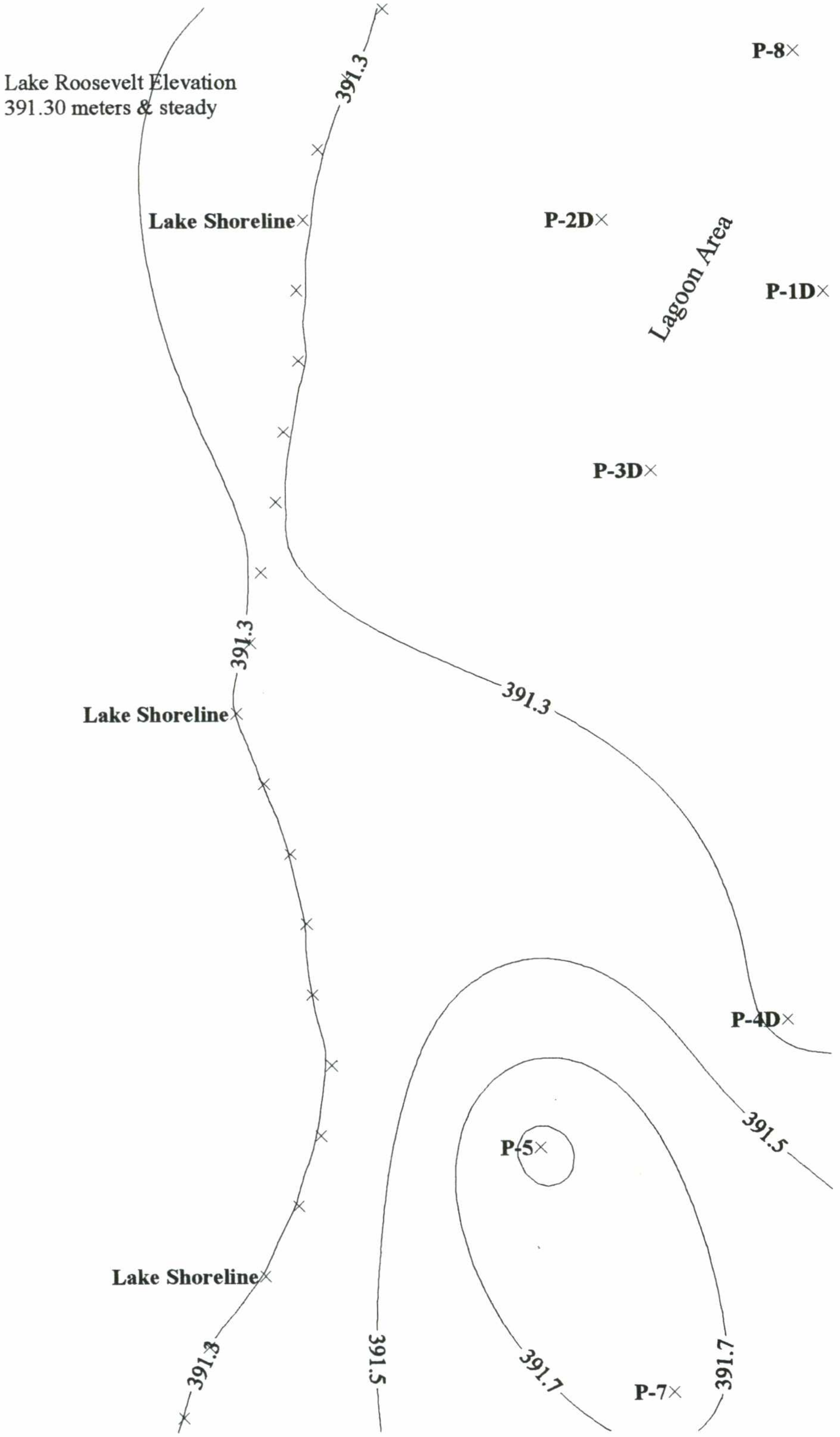


Groundwater Elevation Contour Map - 10/12/94
Contour Interval = 0.1 meters

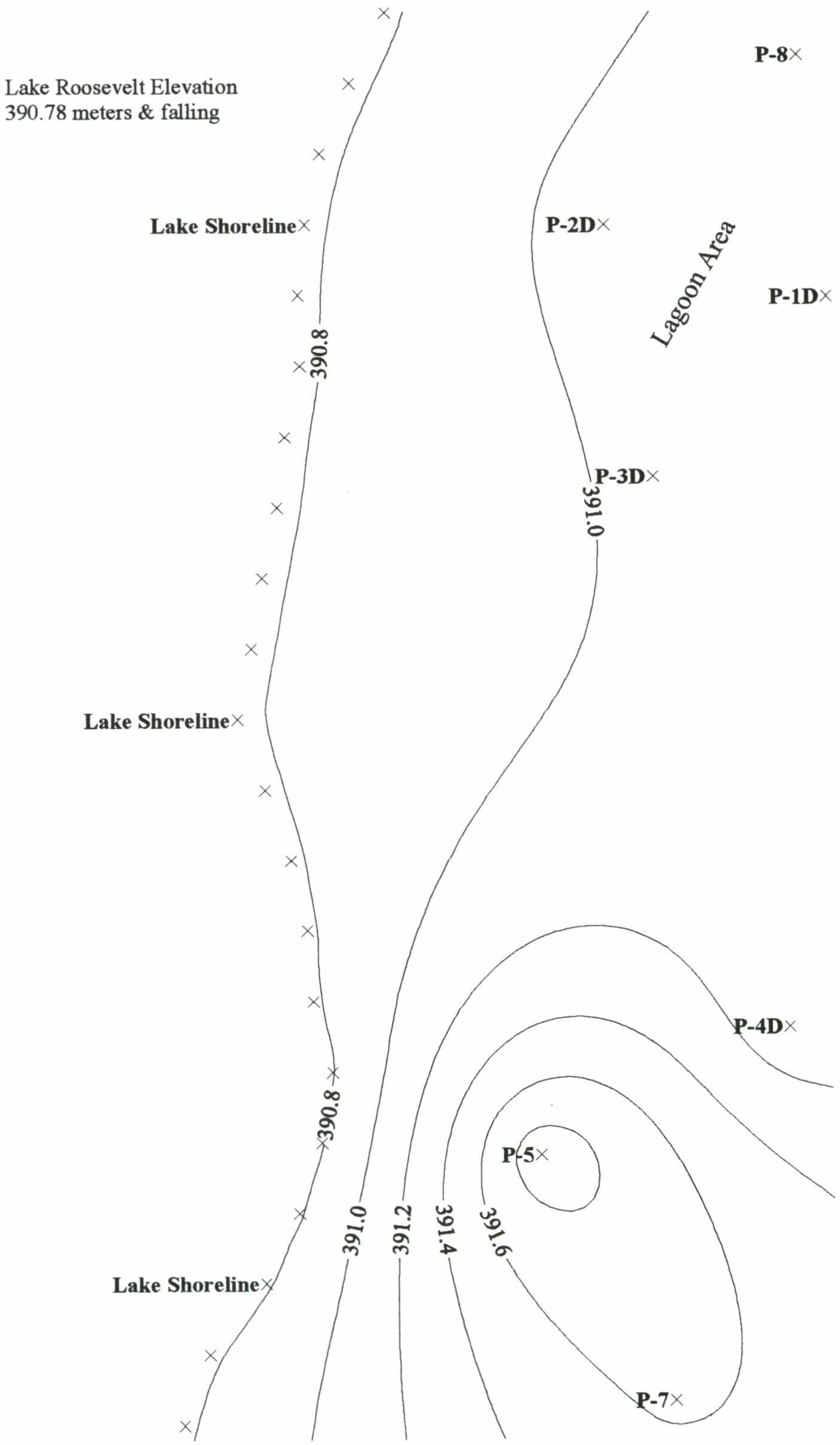


Groundwater Elevation Contour Map - 11/7/94

Contour Interval = 0.1 meters

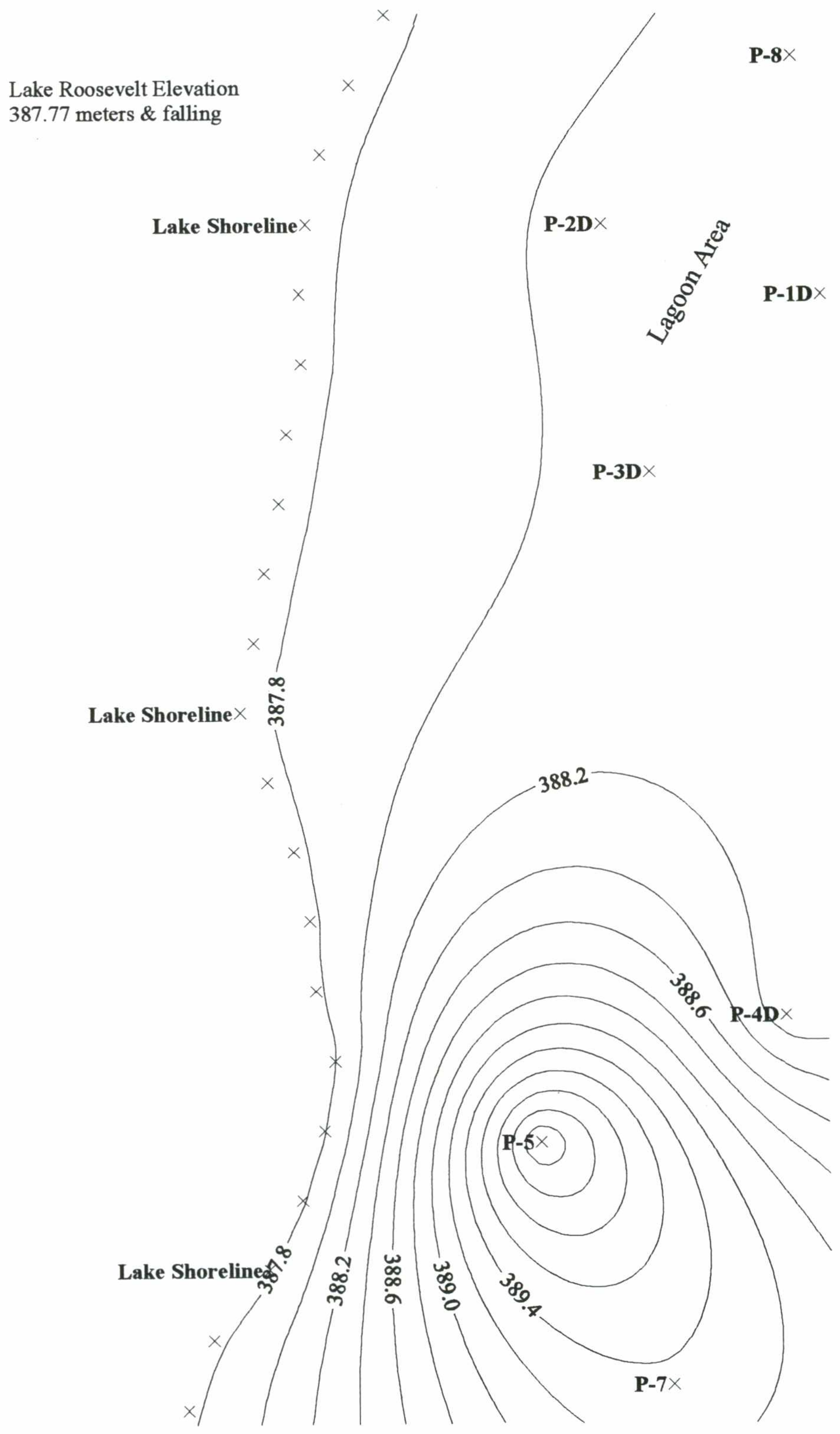


Groundwater Elevation Contour Map - 12/5/94
Contour Interval = 0.2 meters

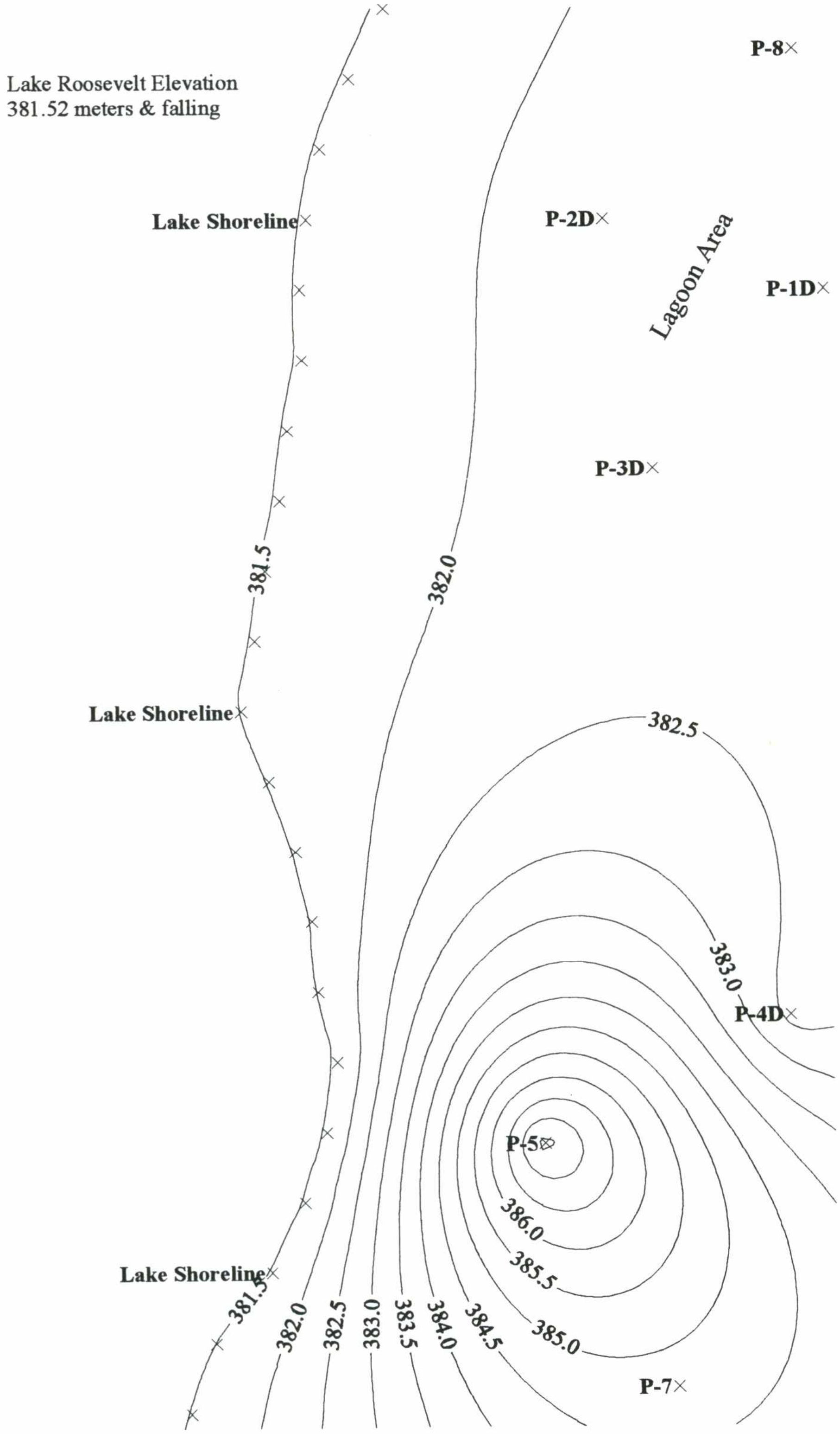


Groundwater Elevation Contour Map - 1/3/95

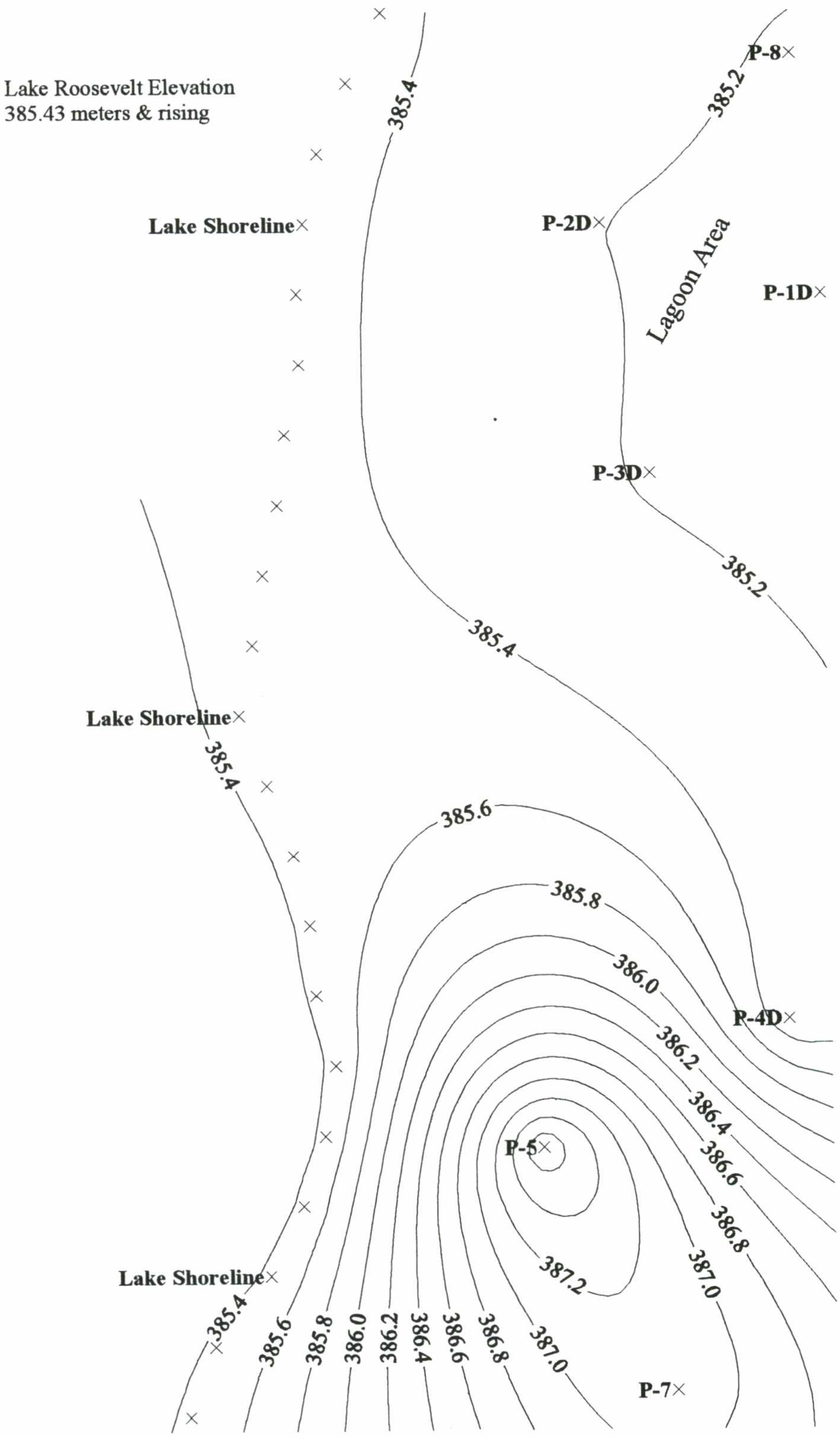
Contour Interval = 0.2 meters



Groundwater Elevation Contour Map - 2/7/95
Contour Interval = 0.2 meters

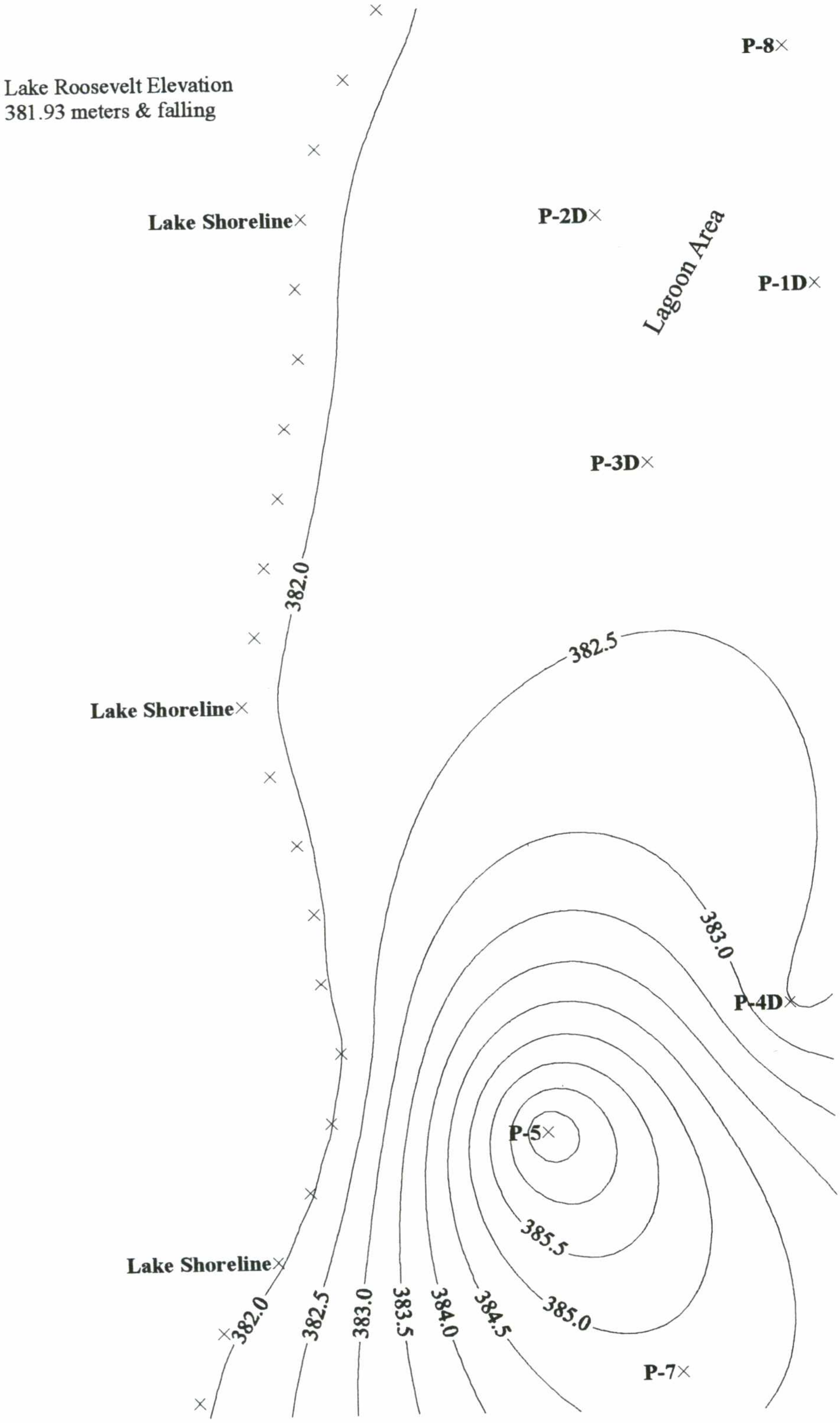


Groundwater Elevation Contour Map - 3/8/95
Contour Interval = 0.5 meters

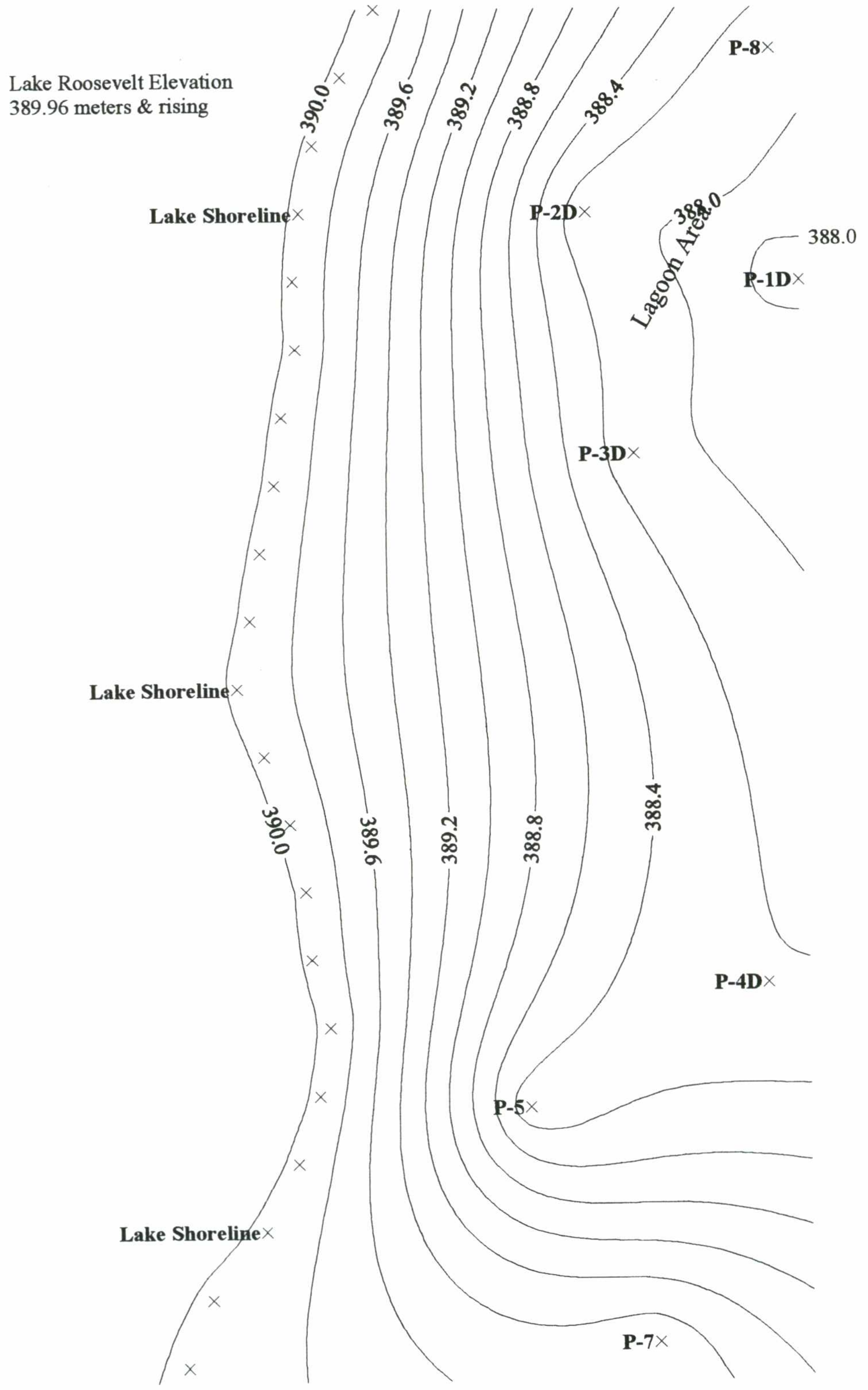


Groundwater Elevation Contour Map - 4/11/95

Contour Interval = 0.2 meters

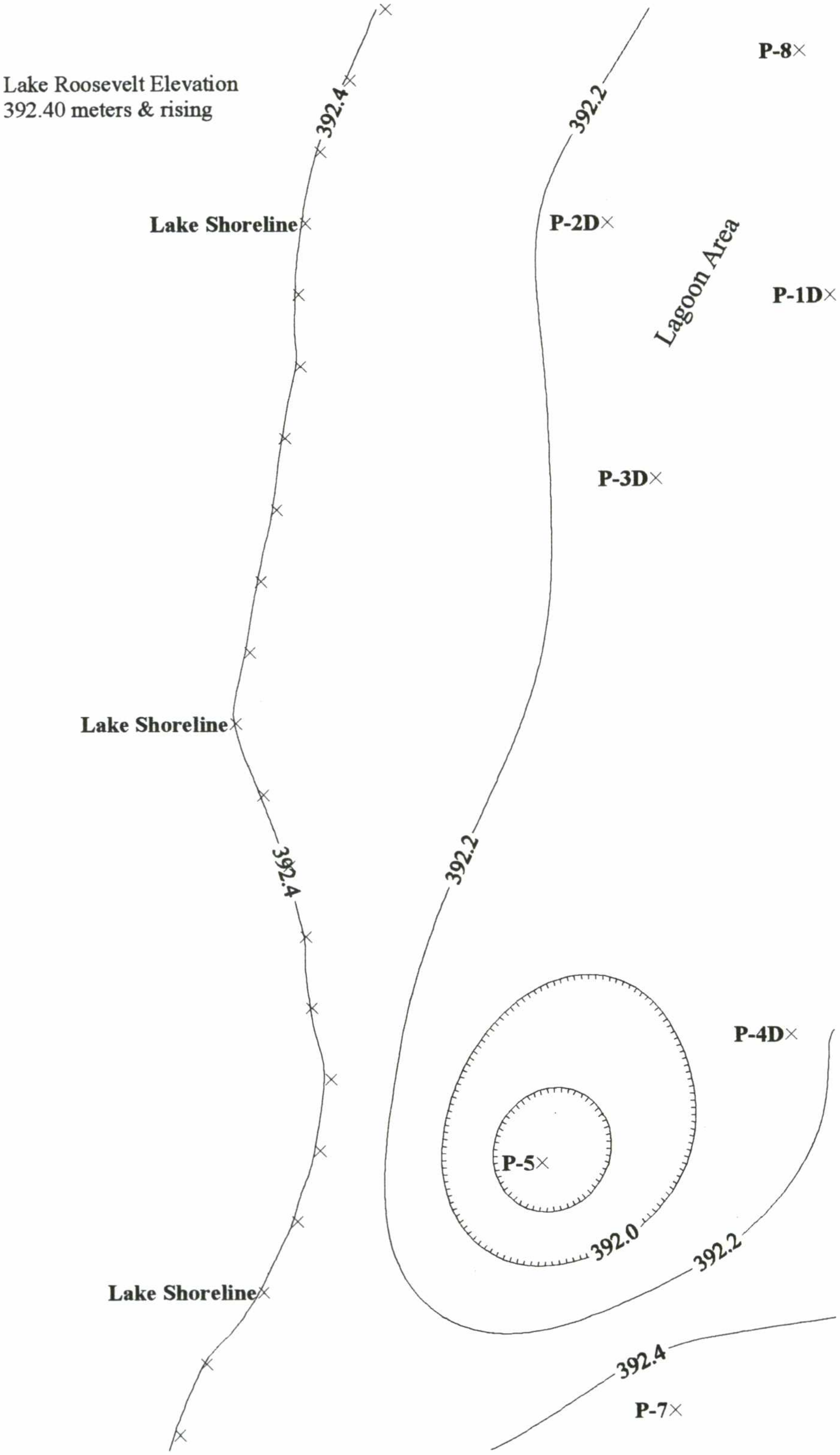


Groundwater Elevation Contour Map - 5/9/95
Contour Interval = 0.5 meters



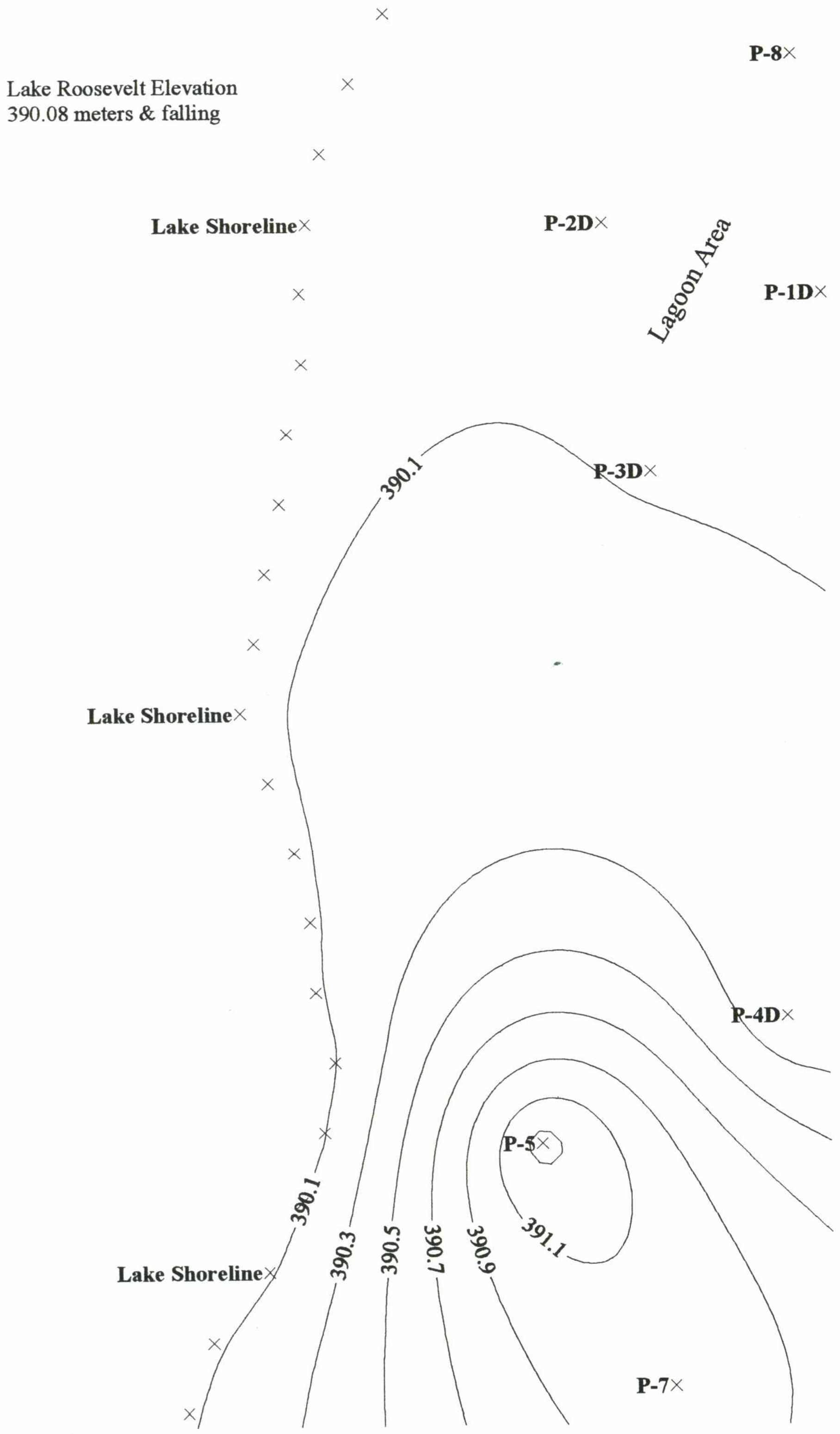
Groundwater Elevation Contour Map - 6/8/95

Contour Interval = 0.2 meters



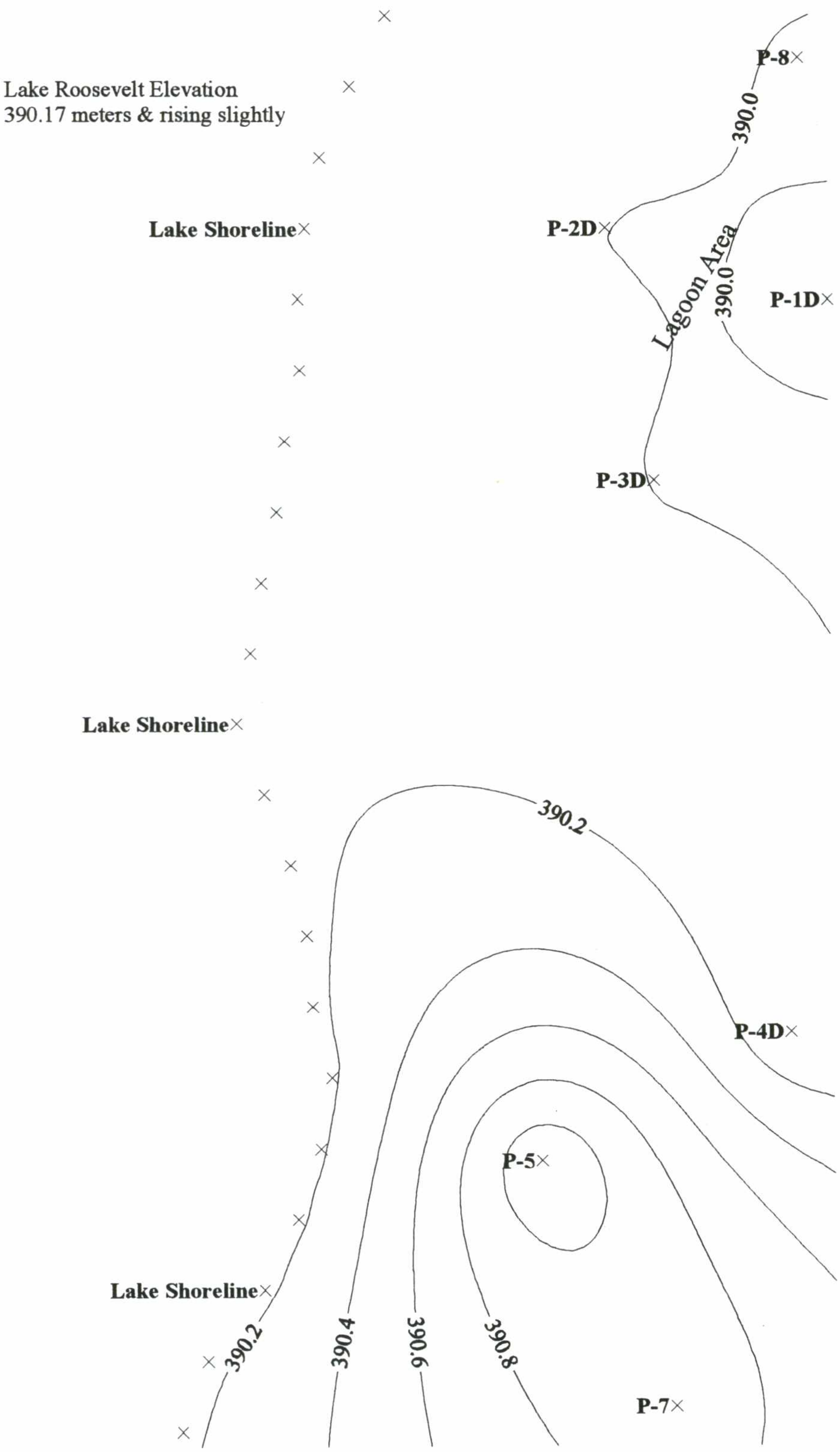
Groundwater Elevation Contour Map - 7/11/95

Contour Interval = 0.2 meters

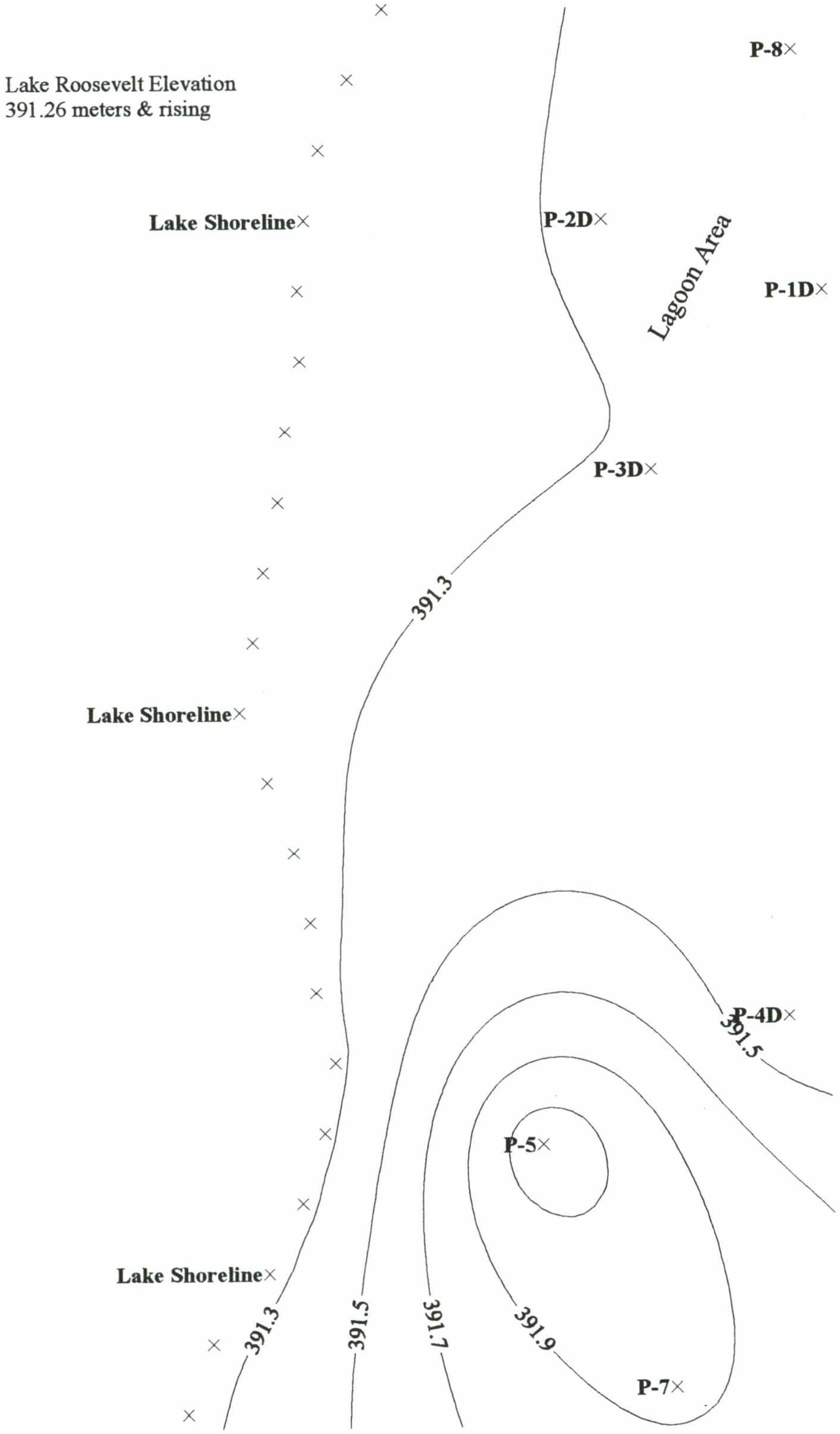


Groundwater Elevation Contour Map - 8/9/95

Contour Interval = 0.2 meters

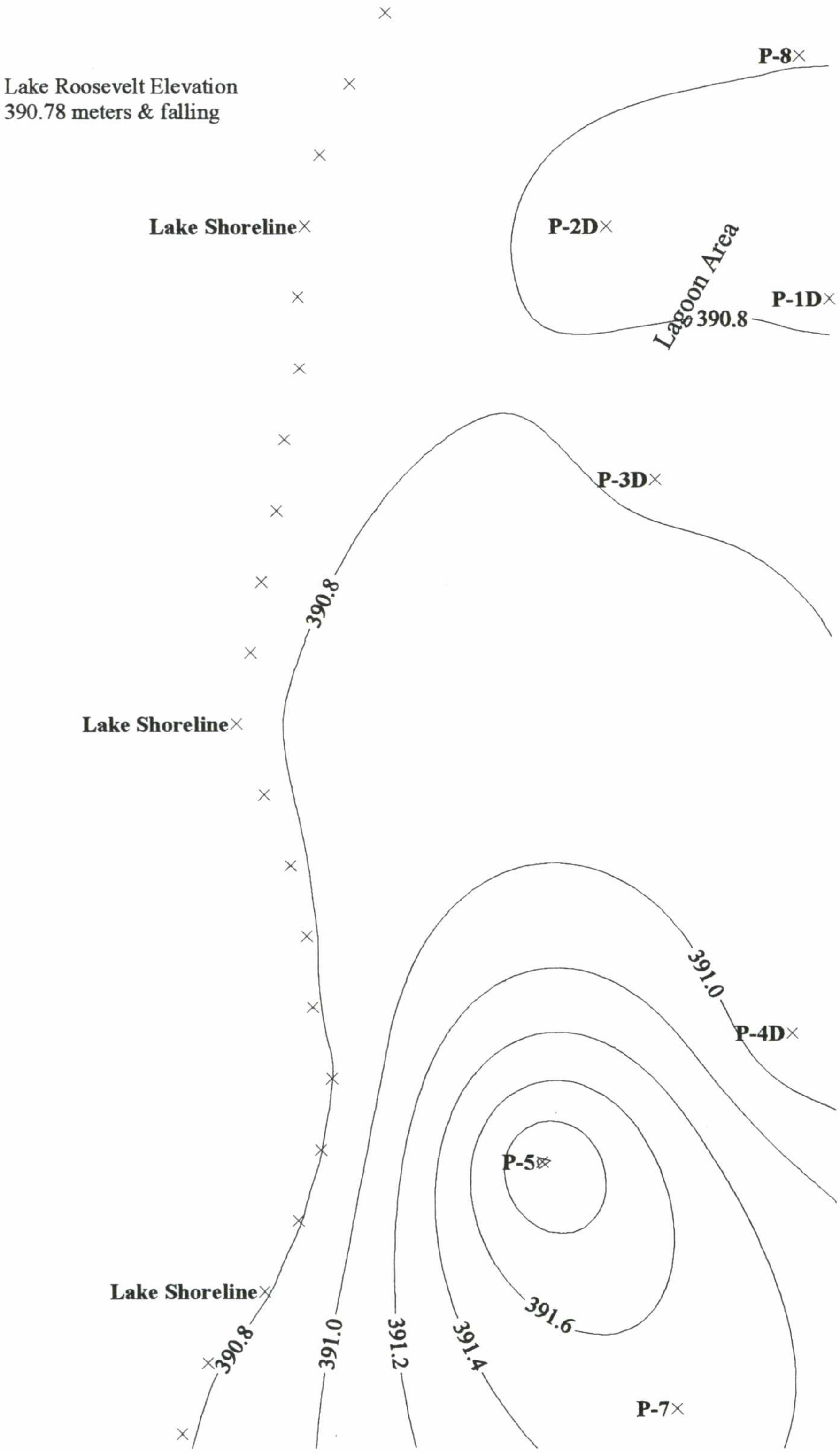


Groundwater Elevation Contour Map - 9/6/95
Contour Interval = 0.2 meters

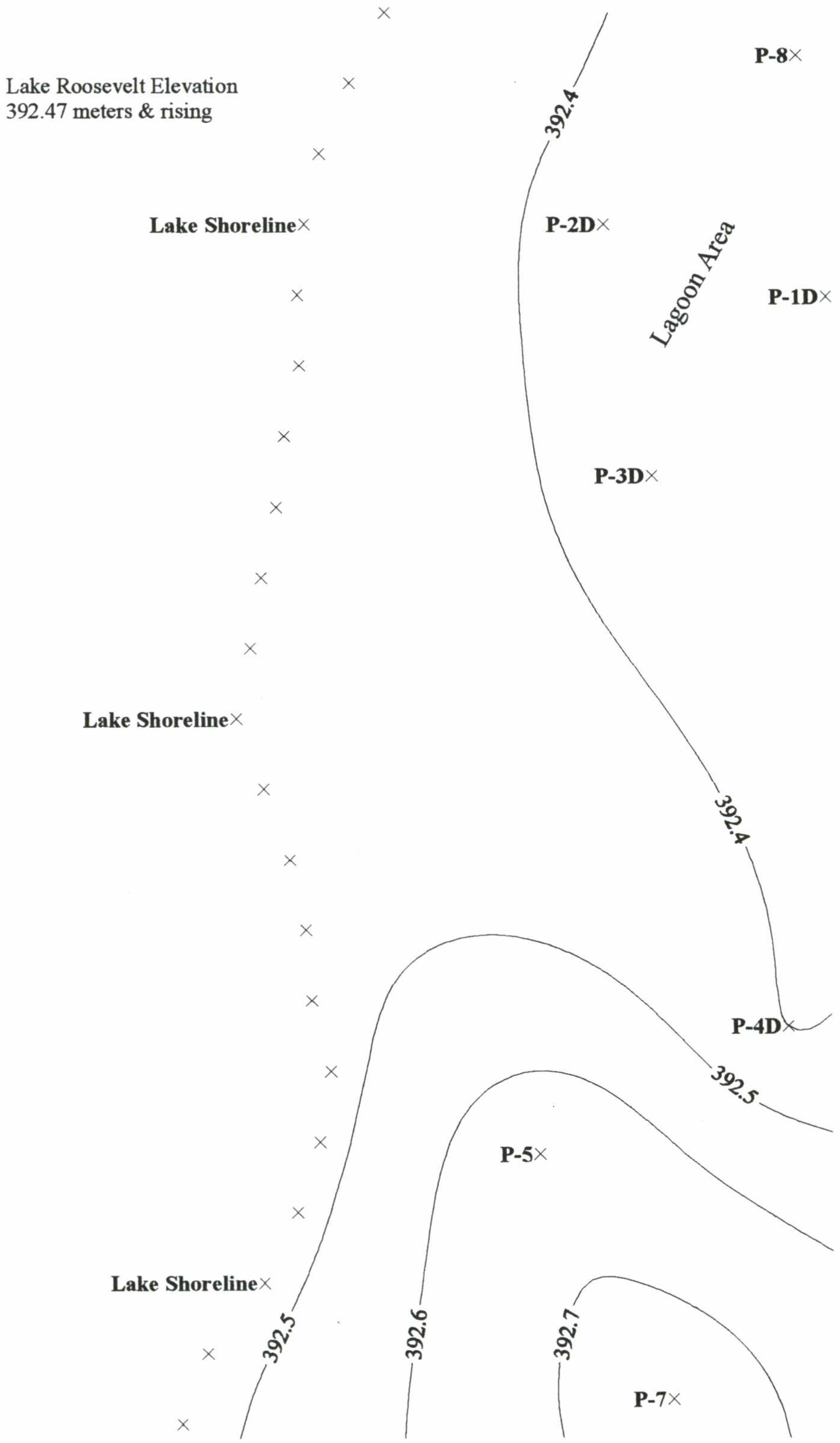


Groundwater Elevation Contour Map - 10/16/95

Contour Interval = 0.2 meters

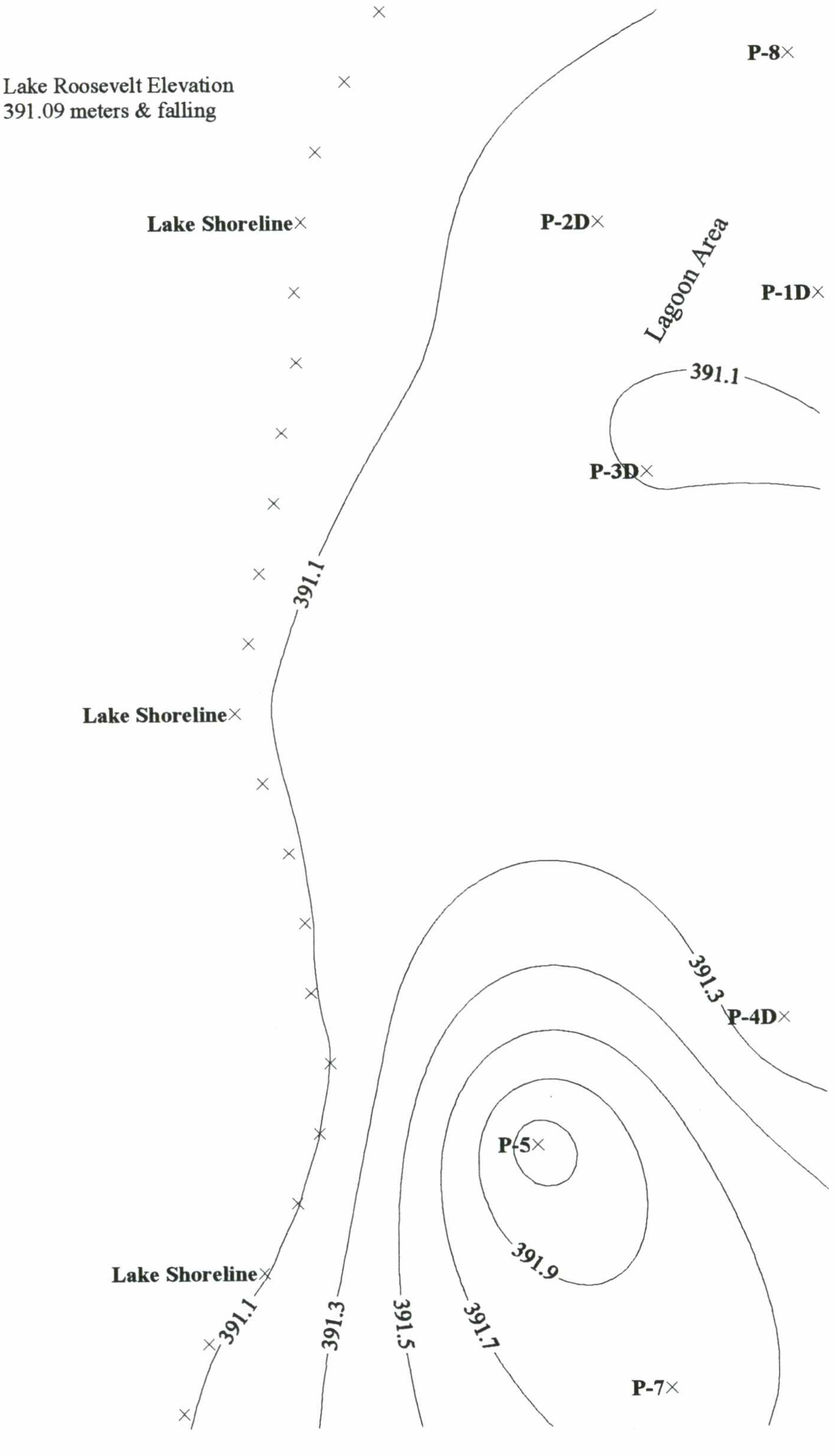


Groundwater Elevation Contour Map - 11/6/95
Contour Interval = 0.2 meters



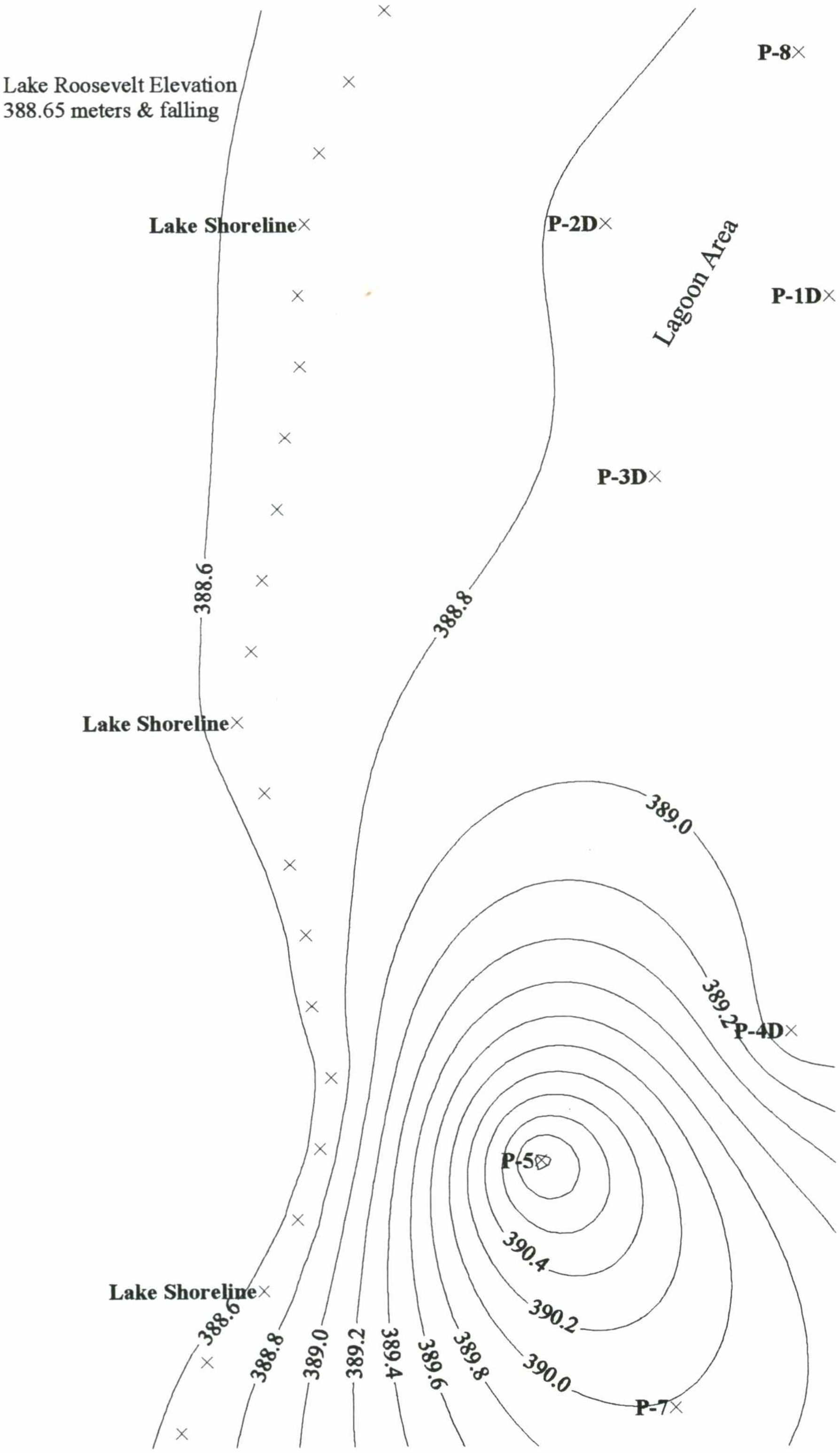
Groundwater Elevation Contour Map - 12/5/95

Contour Interval = 0.1 meters



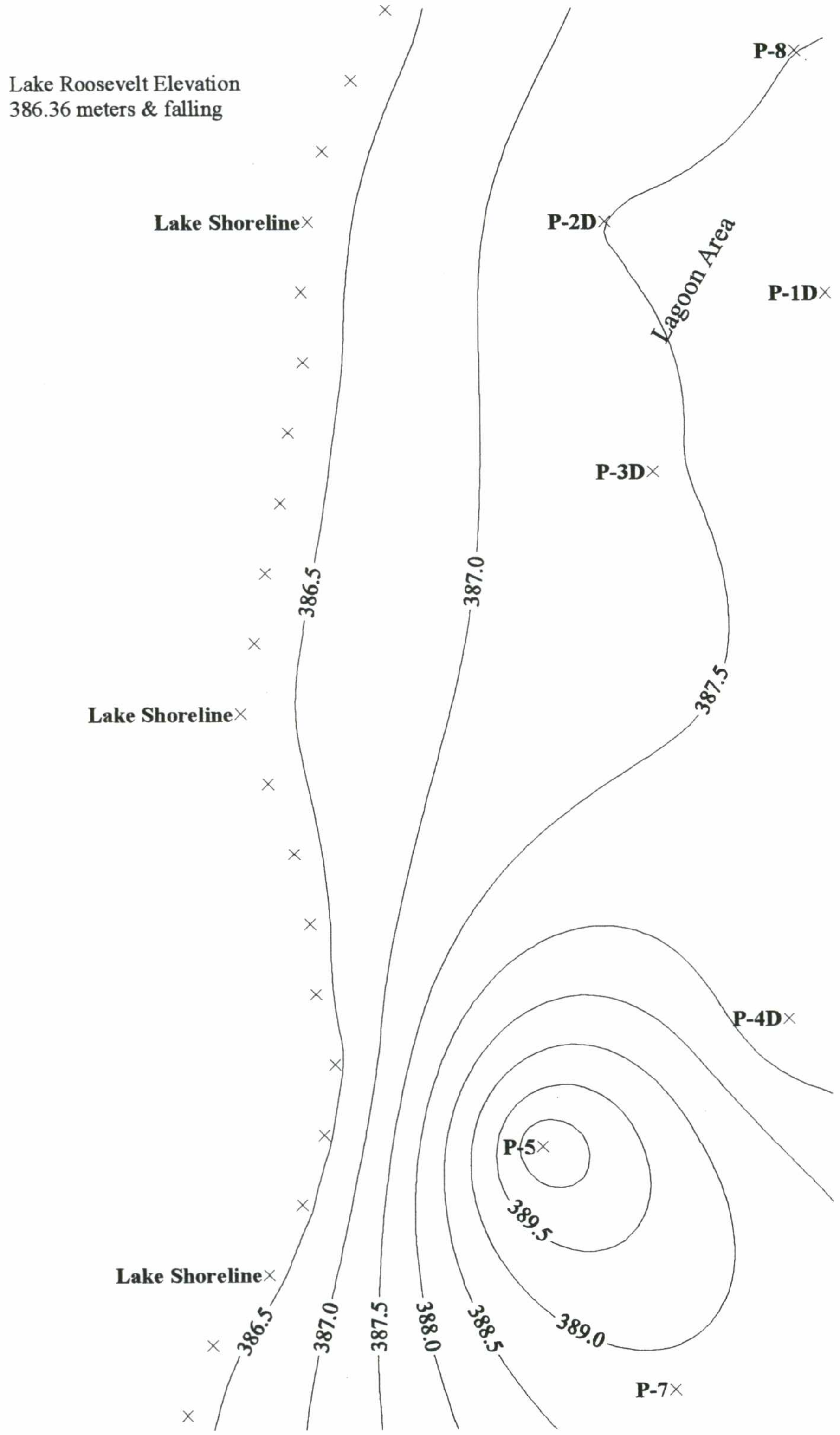
Groundwater Elevation Contour Map - 1/8/96

Contour Interval = 0.2 meters



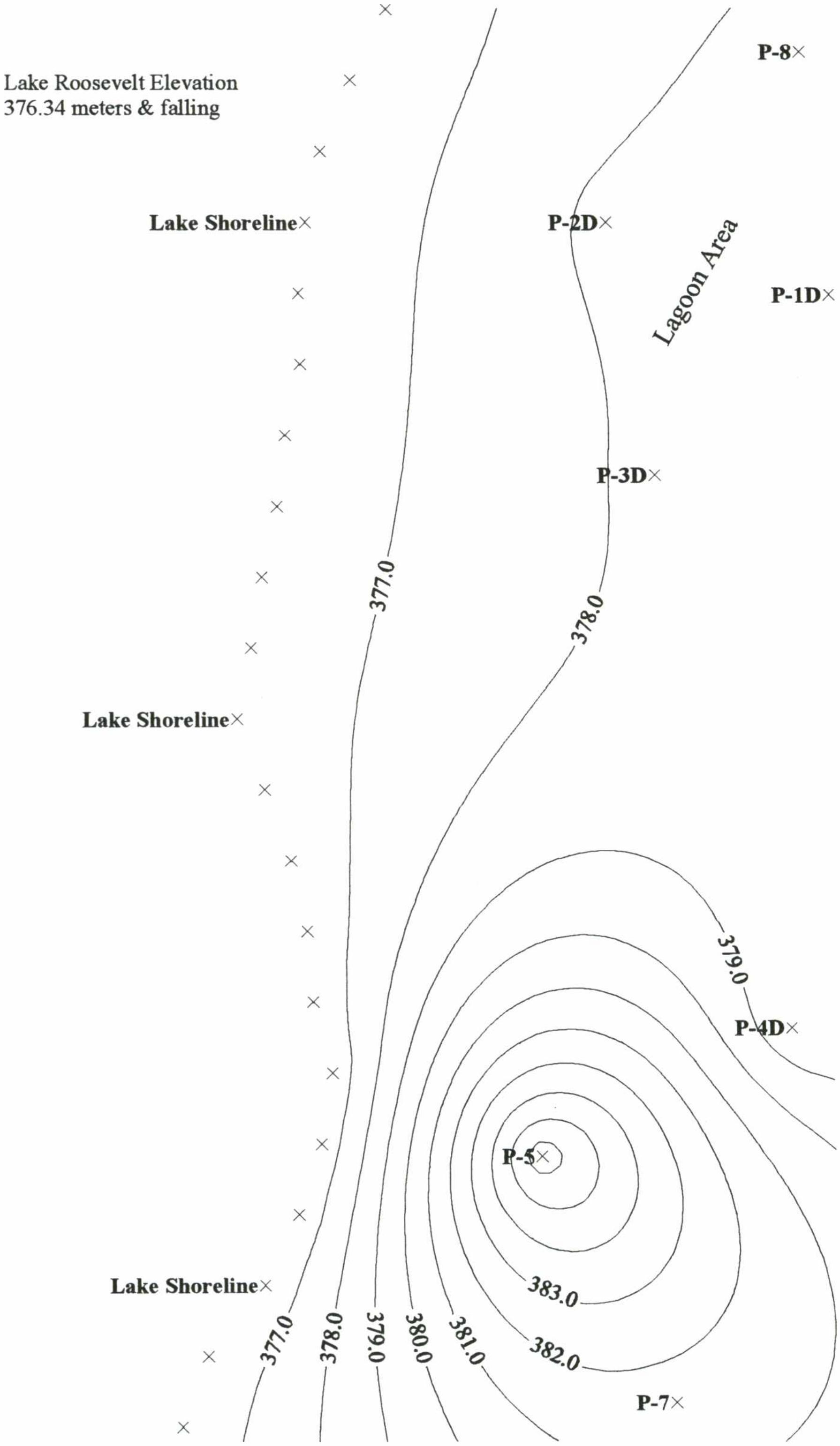
Groundwater Elevation Contour Map - 2/6/96

Contour Interval = 0.2 meters

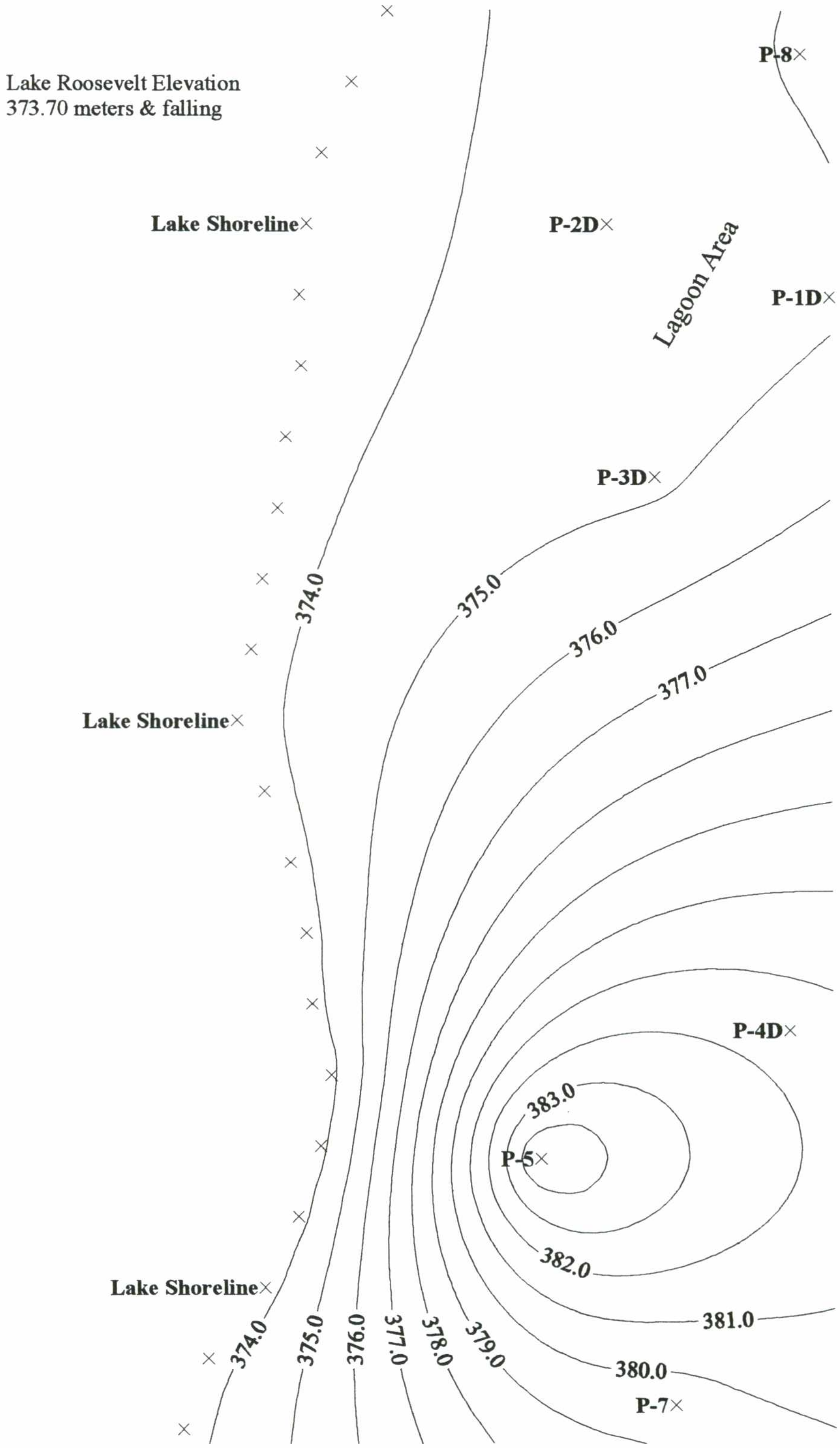


Groundwater Elevation Contour Map - 3/6/96

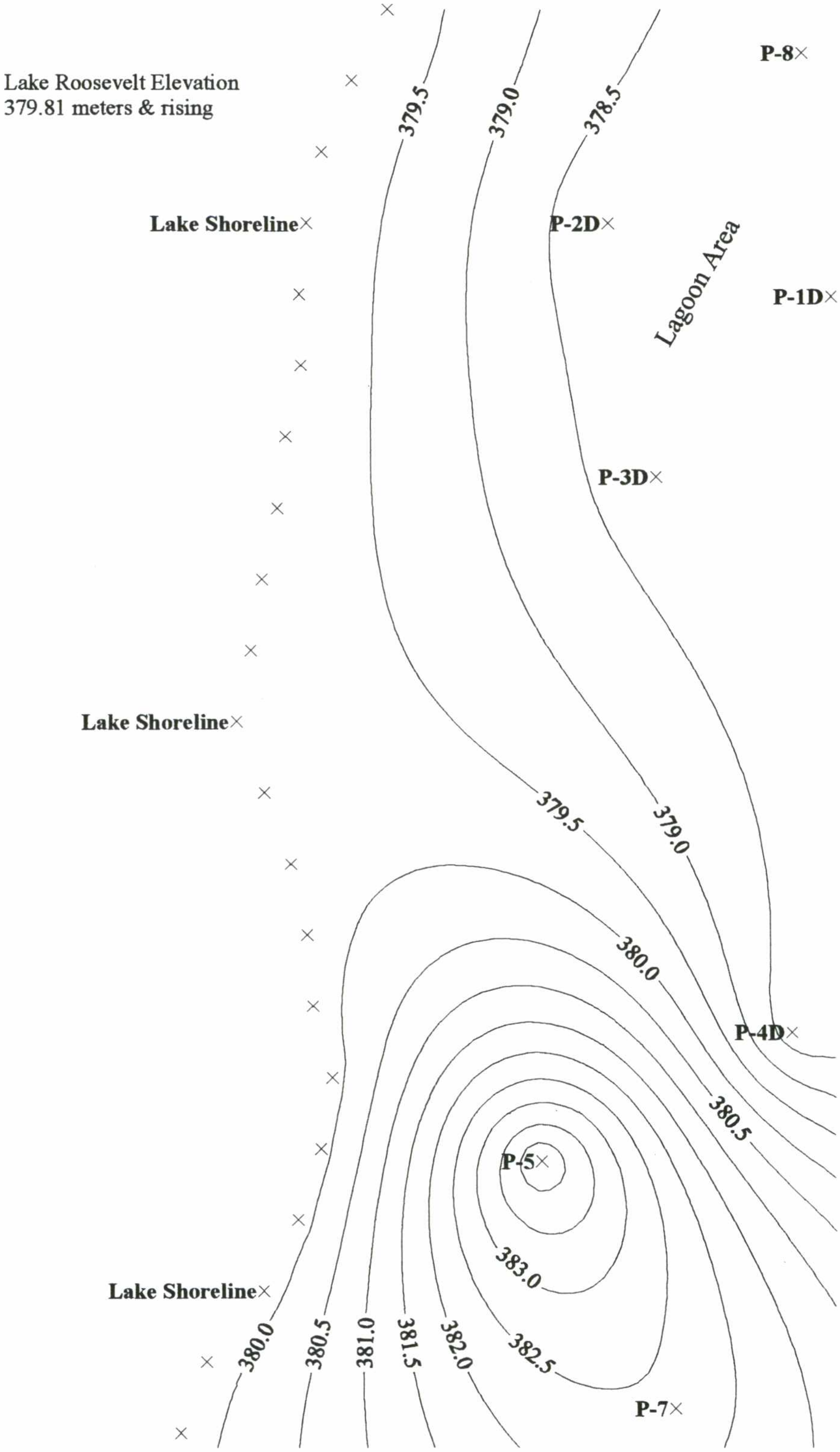
Contour Interval = 0.5 meters



Groundwater Elevation Contour Map - 4/9/96
Contour Interval = 1.0 meters

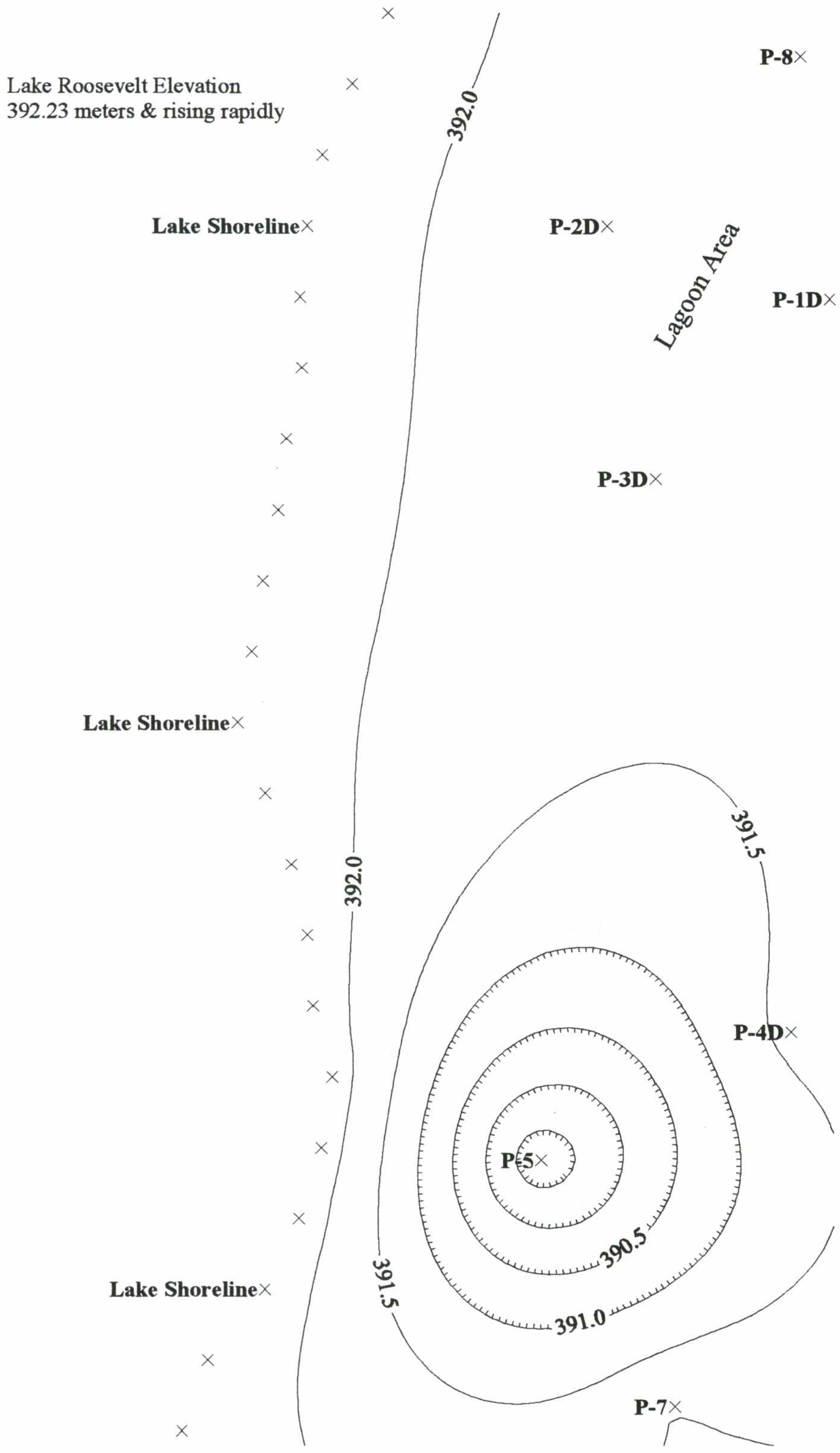


Groundwater Elevation Contour Map - 5/7/96
Contour Interval = 1.0 meters



Groundwater Elevation Contour Map - 6/4/96

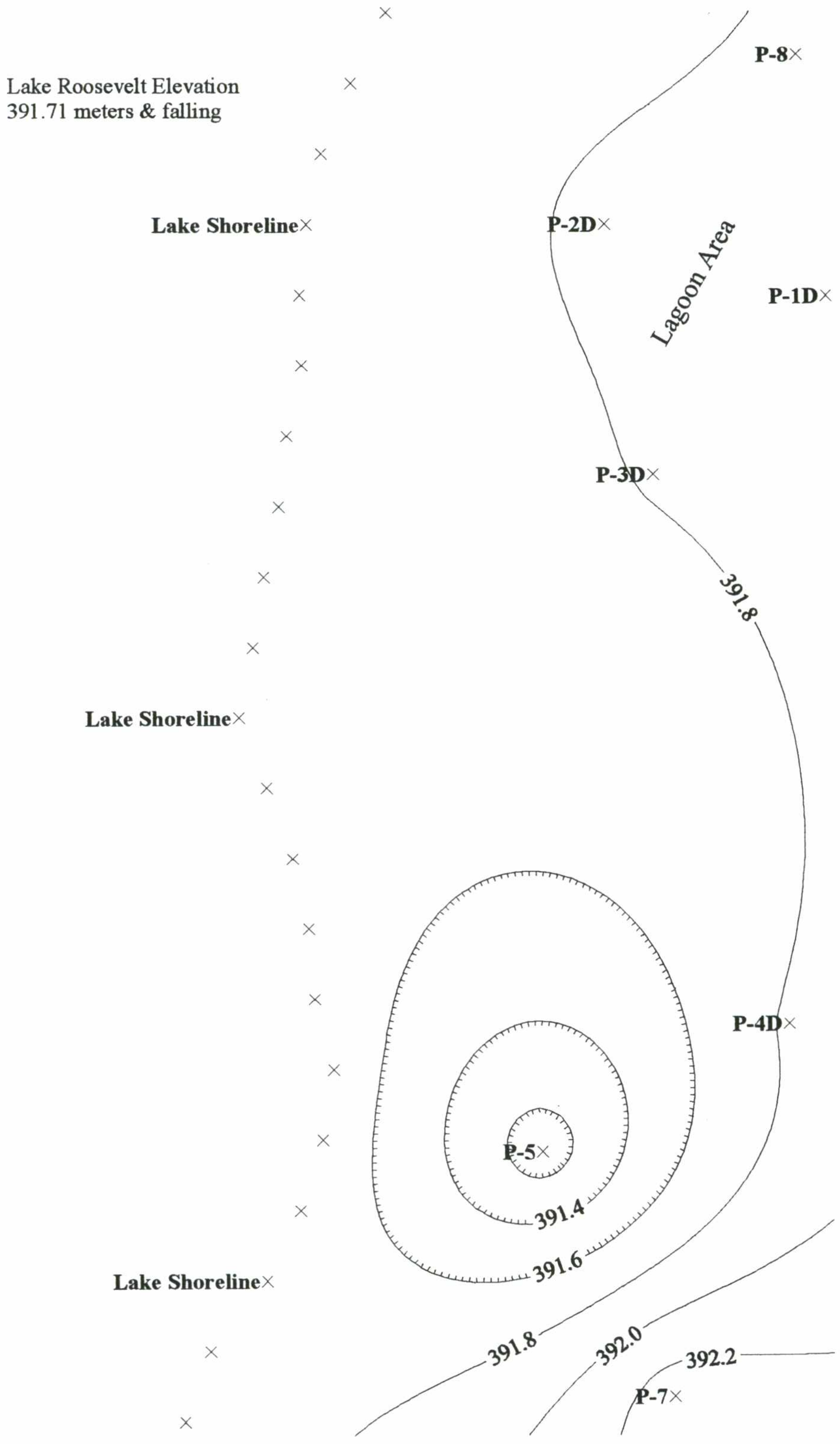
Contour Interval = 0.5 meters



Lake Roosevelt Elevation
392.23 meters & rising rapidly

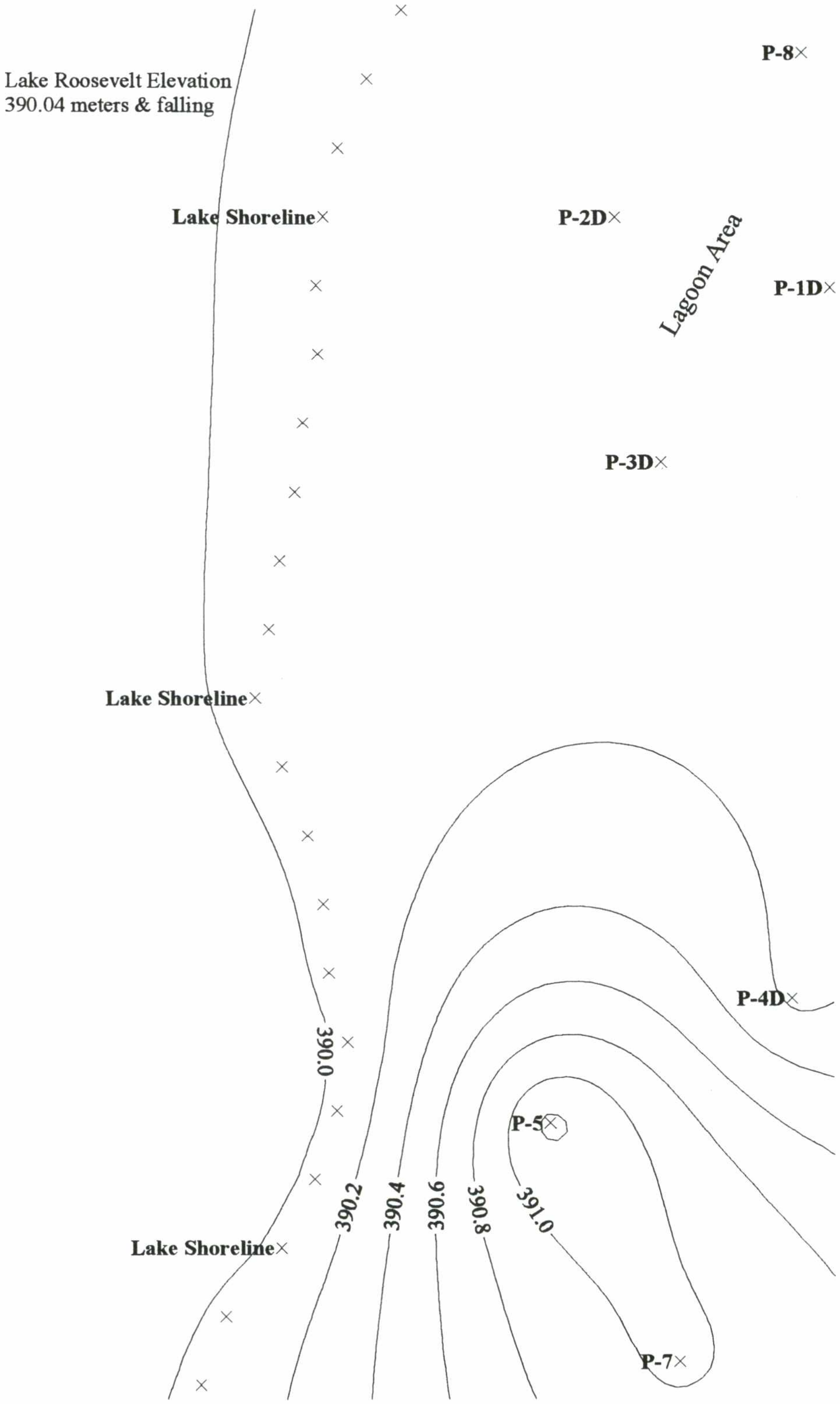
Groundwater Elevation Contour Map - 7/10/96

Contour Interval = 0.5 meters



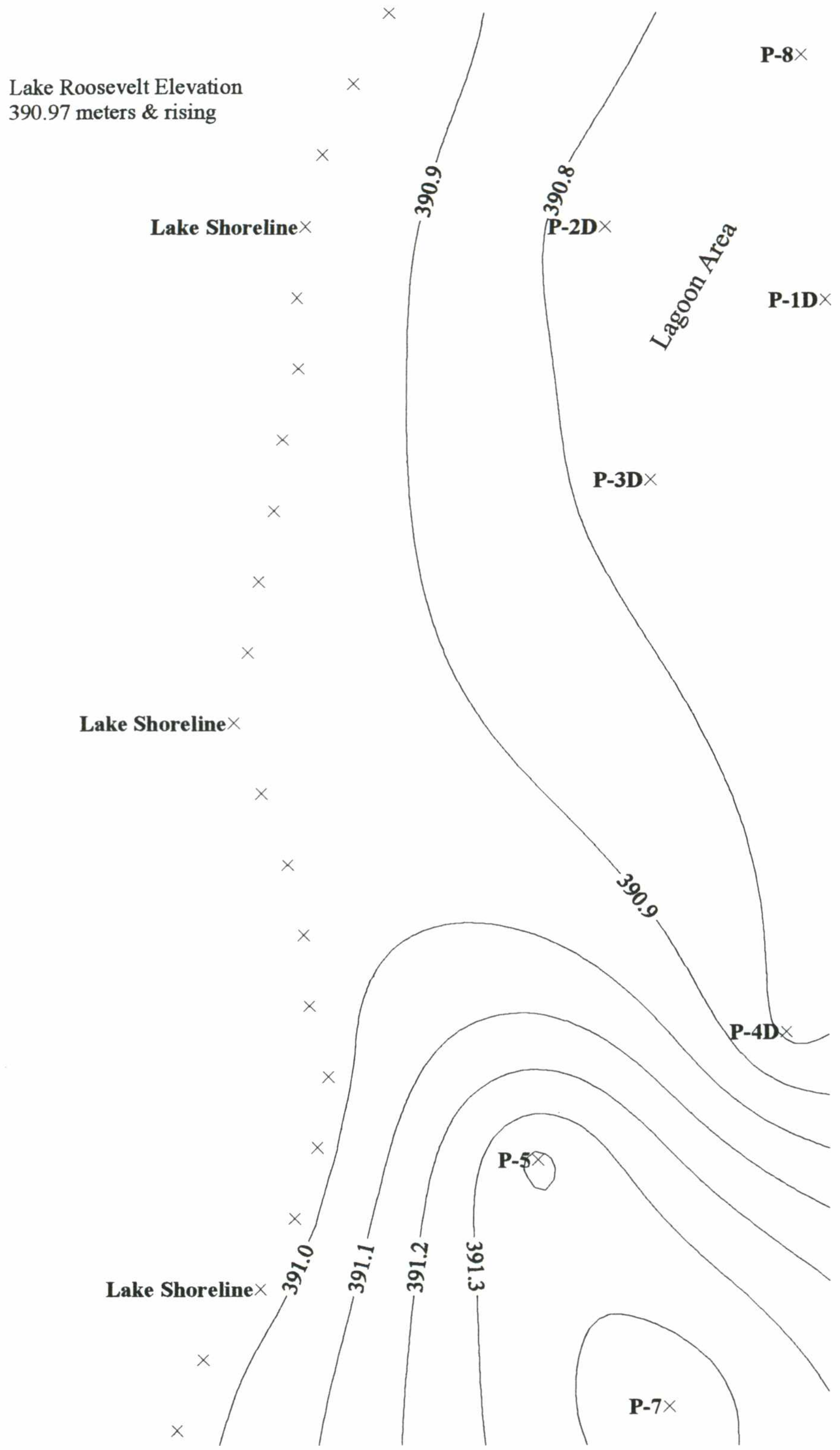
Groundwater Elevation Contour Map - 8/1/96

Contour Interval = 0.2 meters

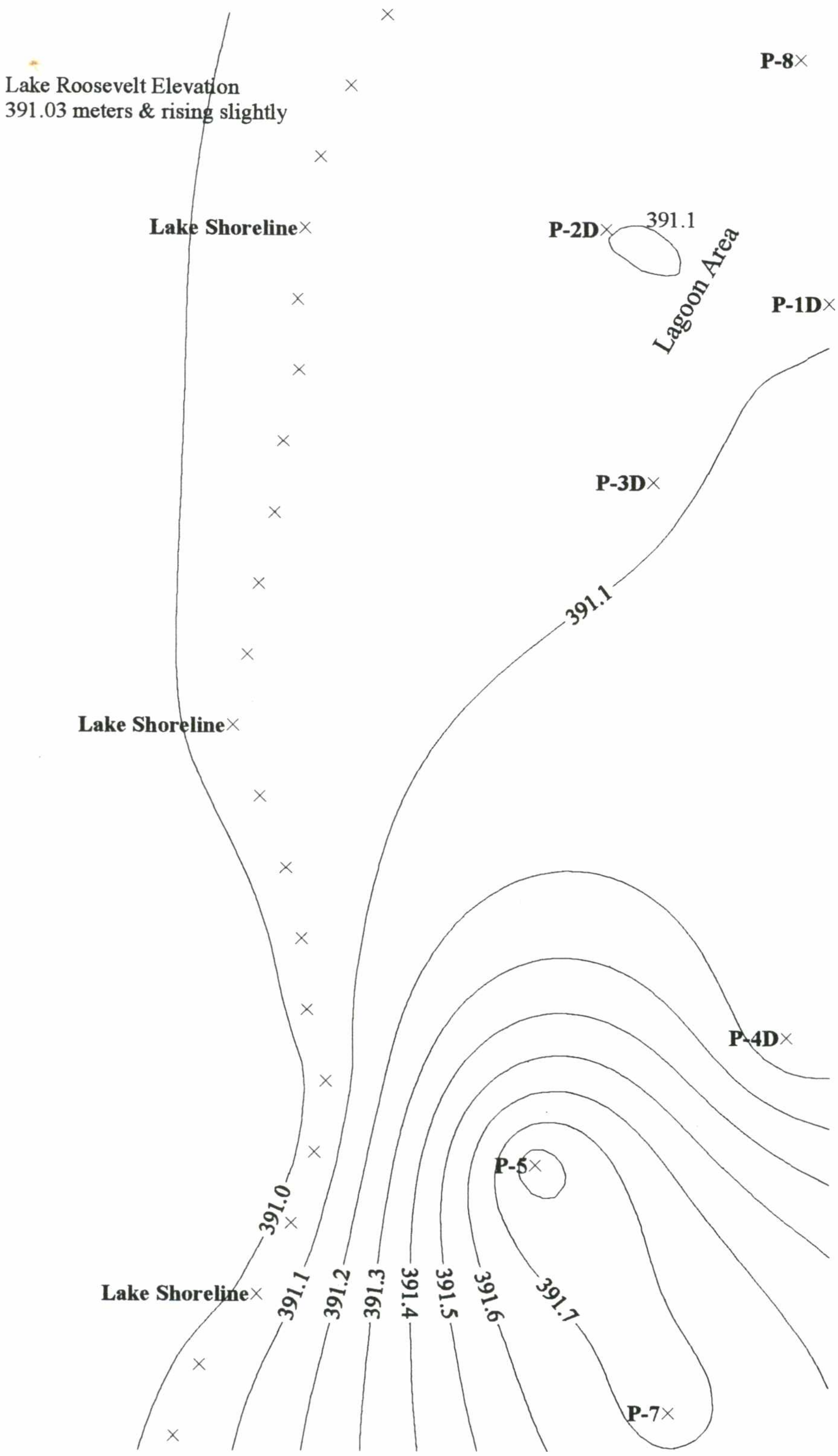


Groundwater Elevation Contour Map - 9/11/96

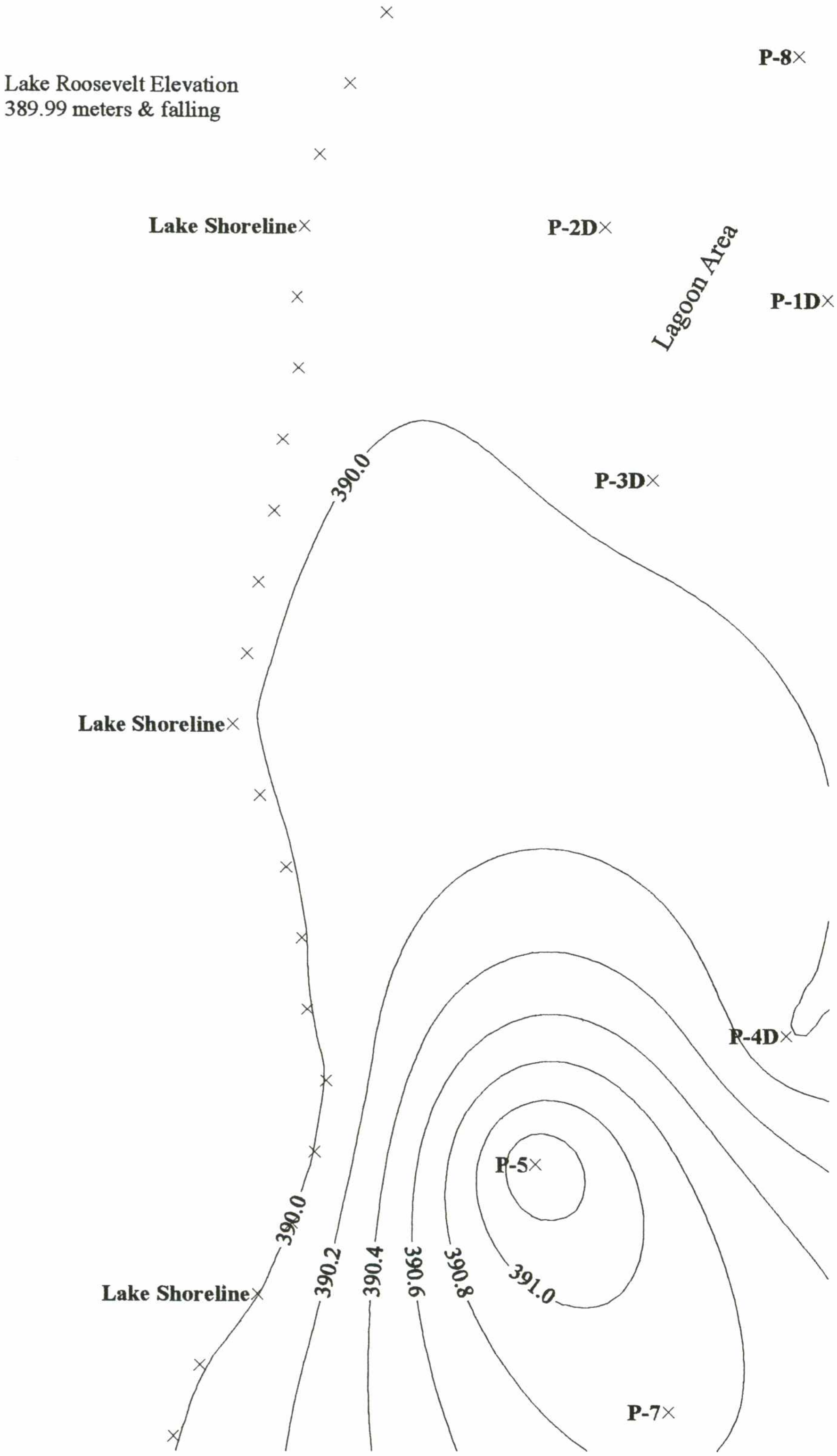
Contour Interval = 0.2 meters



Groundwater Elevation Contour Map - 10/8/96
Contour Interval = 0.1 meters



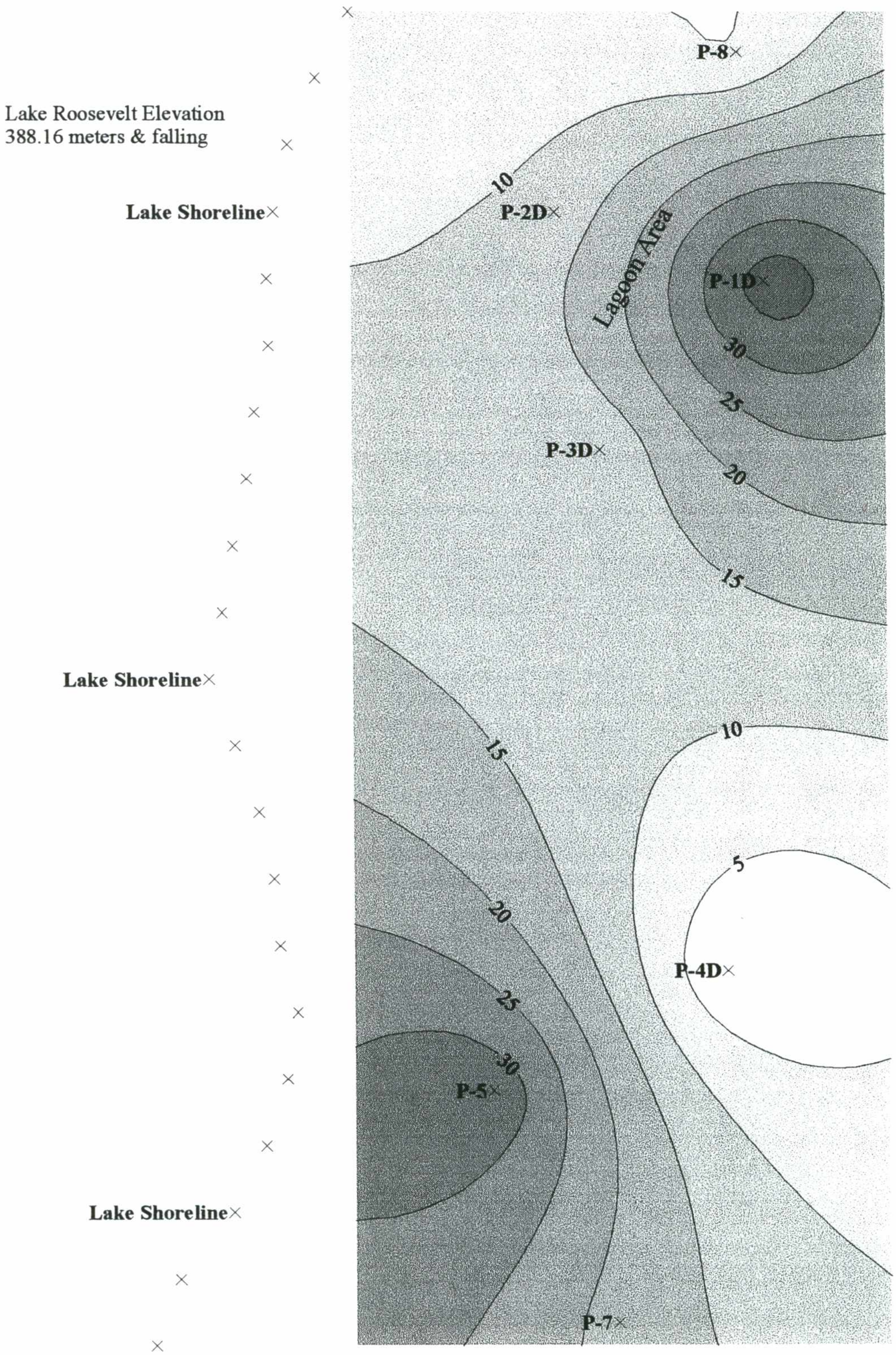
Groundwater Elevation Contour Map - 11/6/96
Contour Interval = 0.1 meters



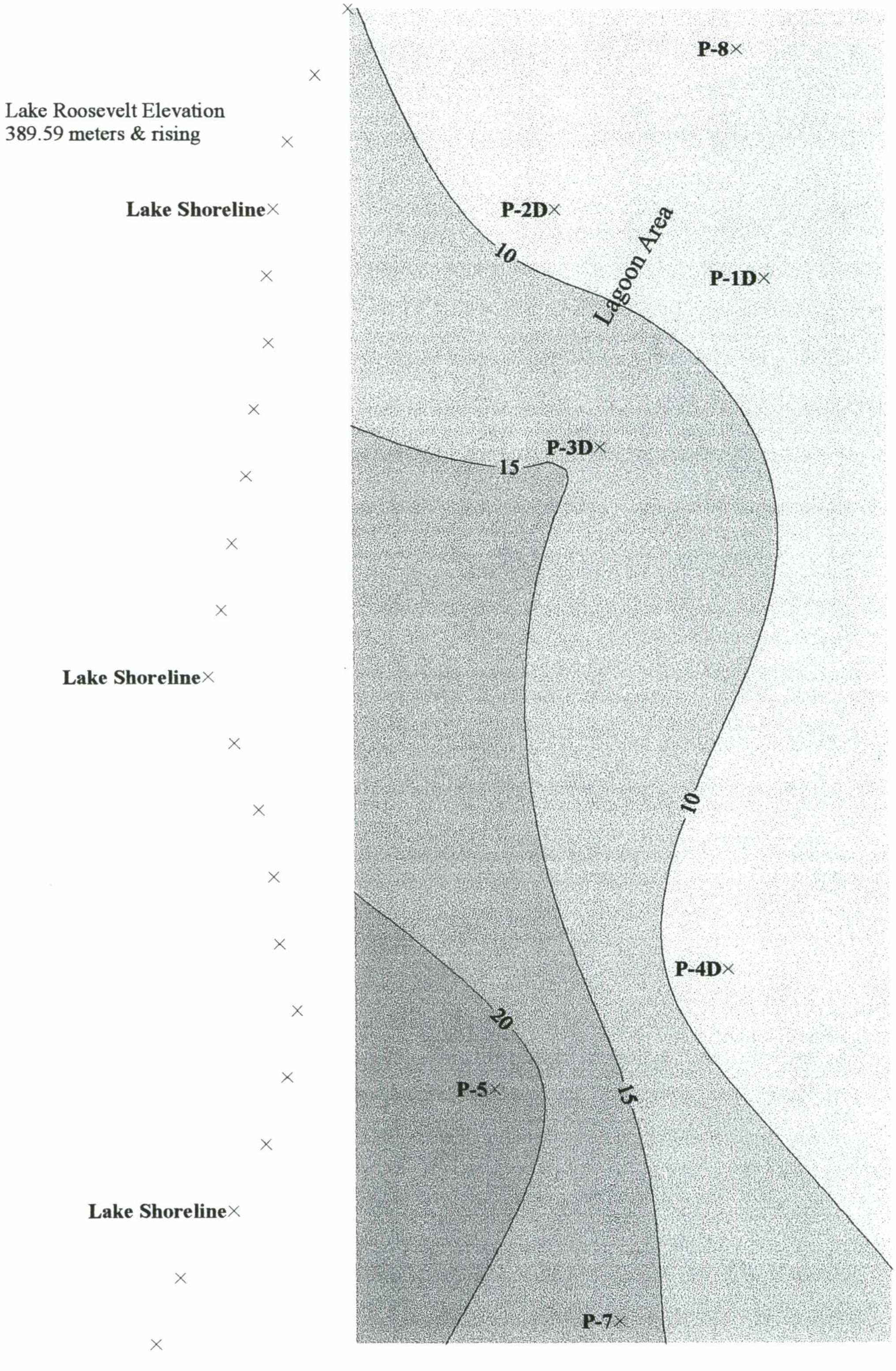
Groundwater Elevation Contour Map - 12/11/96
Contour Interval = 0.2 meters

APPENDIX C. CHEMICAL DISTRIBUTION CONTOUR MAPS

Chemical Oxygen Demand in Groundwater -- Contour Maps



Chemical Oxygen Demand in Groundwater (mg/L) - 6/21/94
Contour Interval = 5 meters

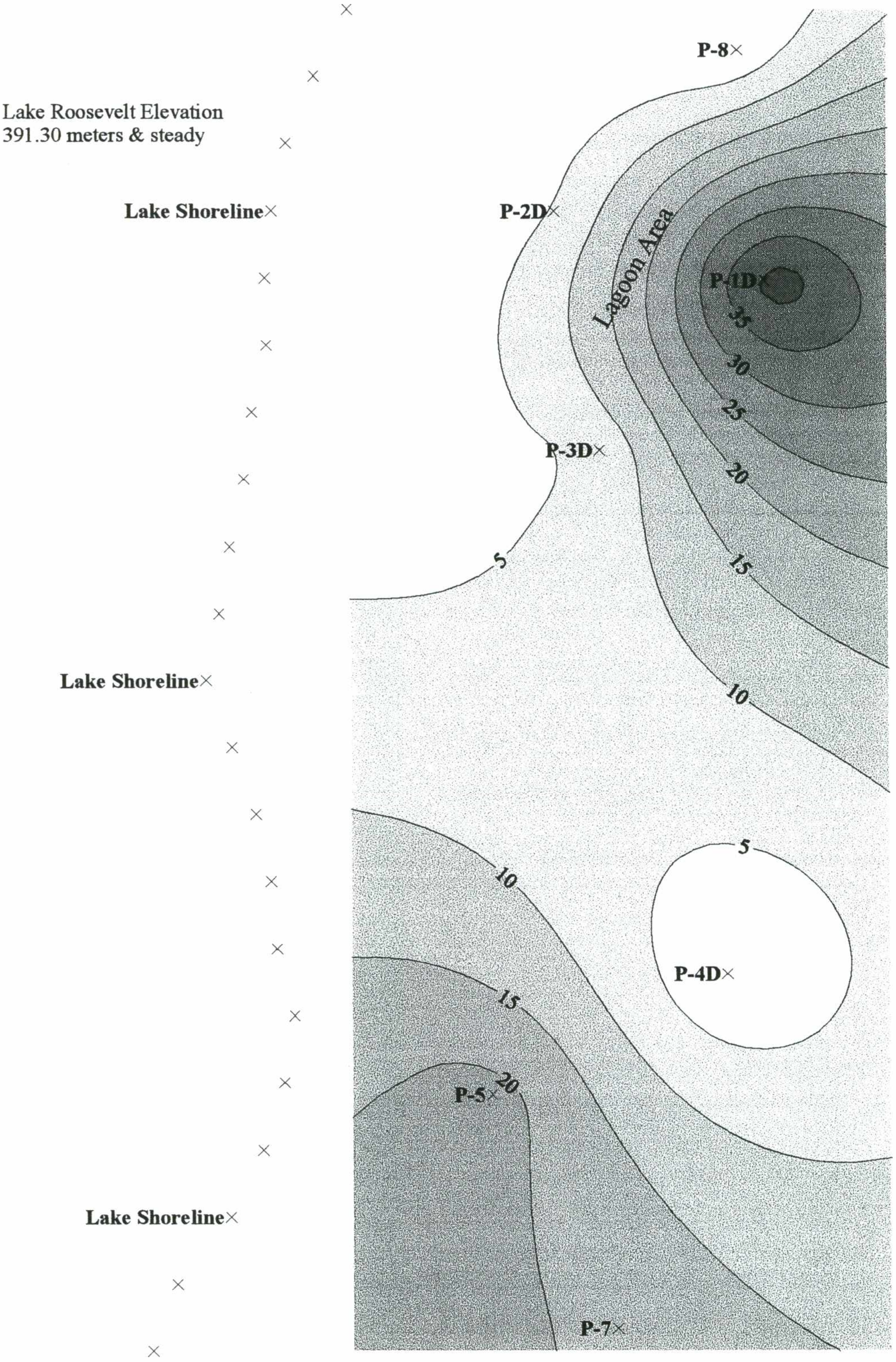


Chemical Oxygen Demand in Groundwater (mg/L) - 9/7/94

Contour Interval = 5 meters

meters

0 50 100 150 200

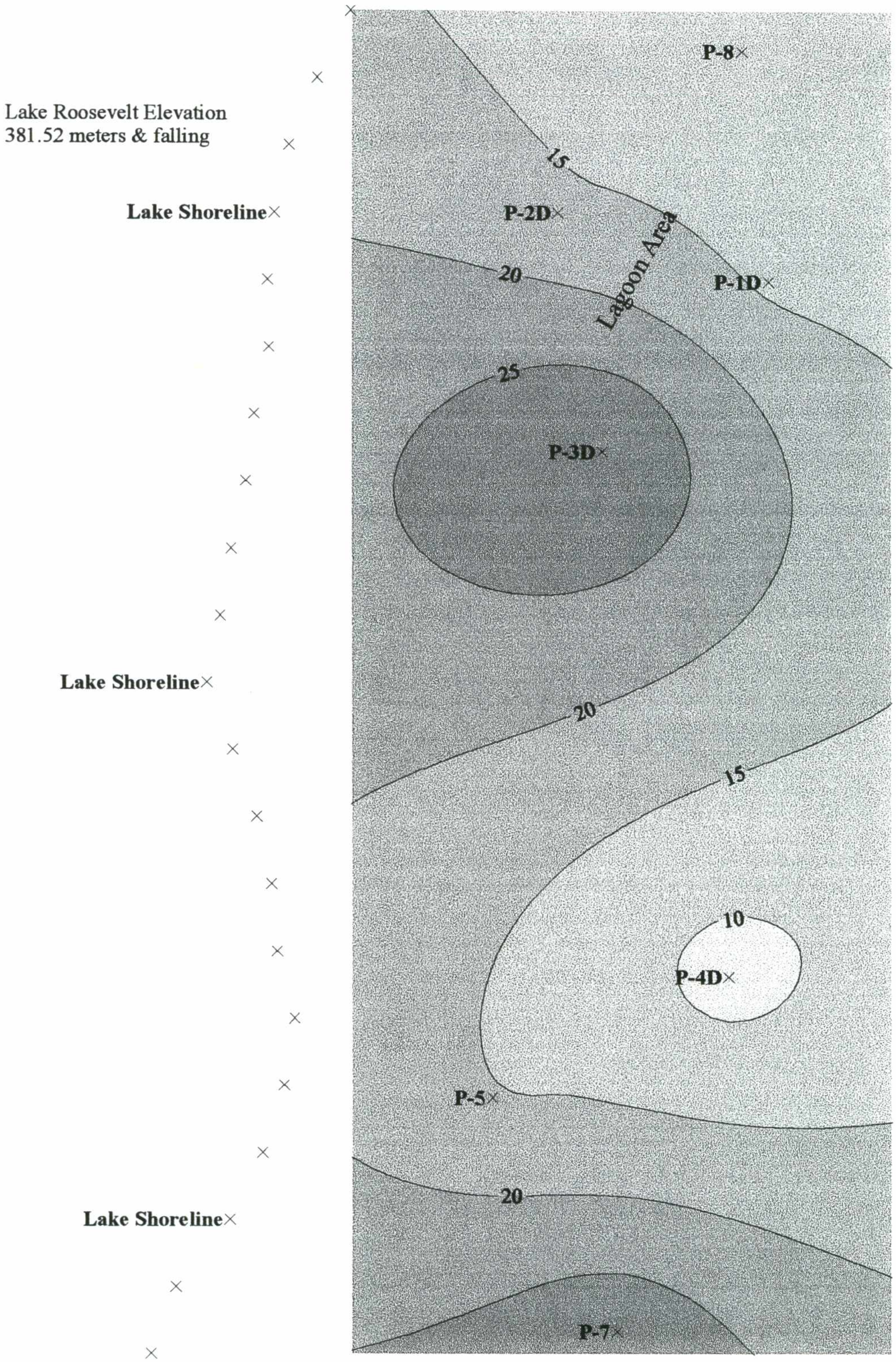


Chemical Oxygen Demand in Groundwater (mg/L) - 12/5/94

Contour Interval = 5 meters

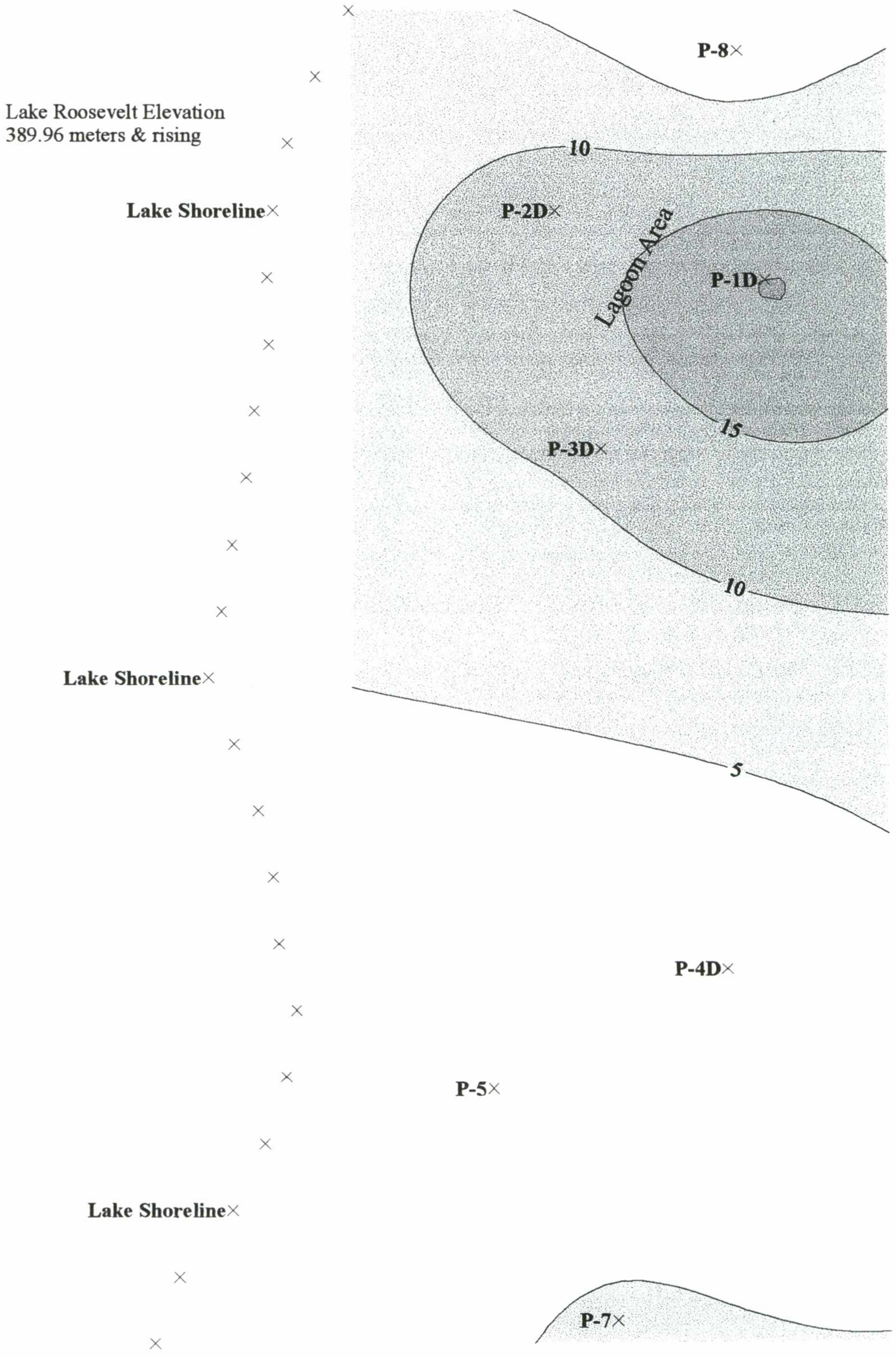
meters

0 50 100 150 200



Chemical Oxygen Demand in Groundwater (mg/L) - 3/9/95

Contour Interval = 5 meters

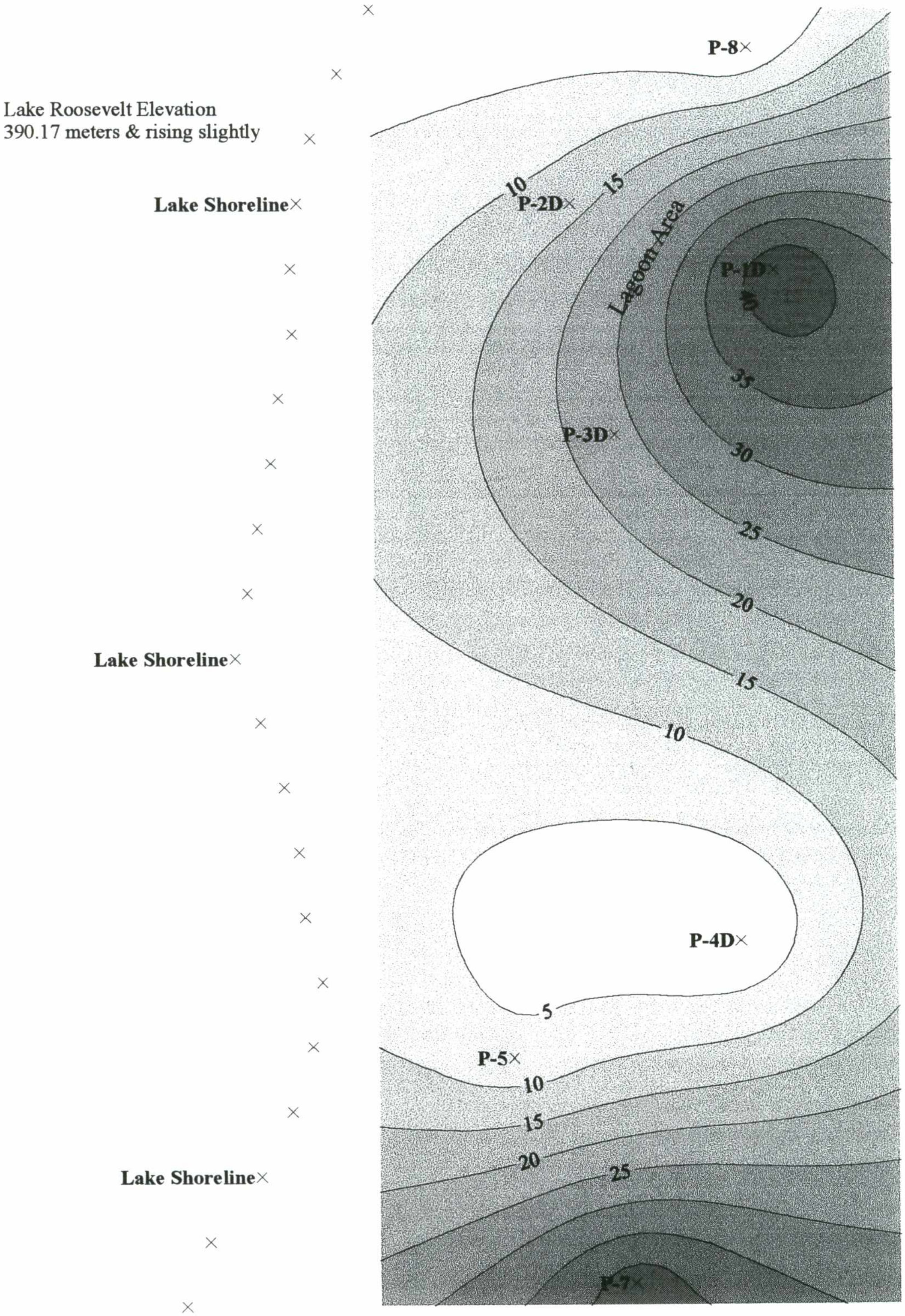


Chemical Oxygen Demand in Groundwater (mg/L) - 6/8/95

Contour Interval = 5 meters

meters

0 50 100 150 200

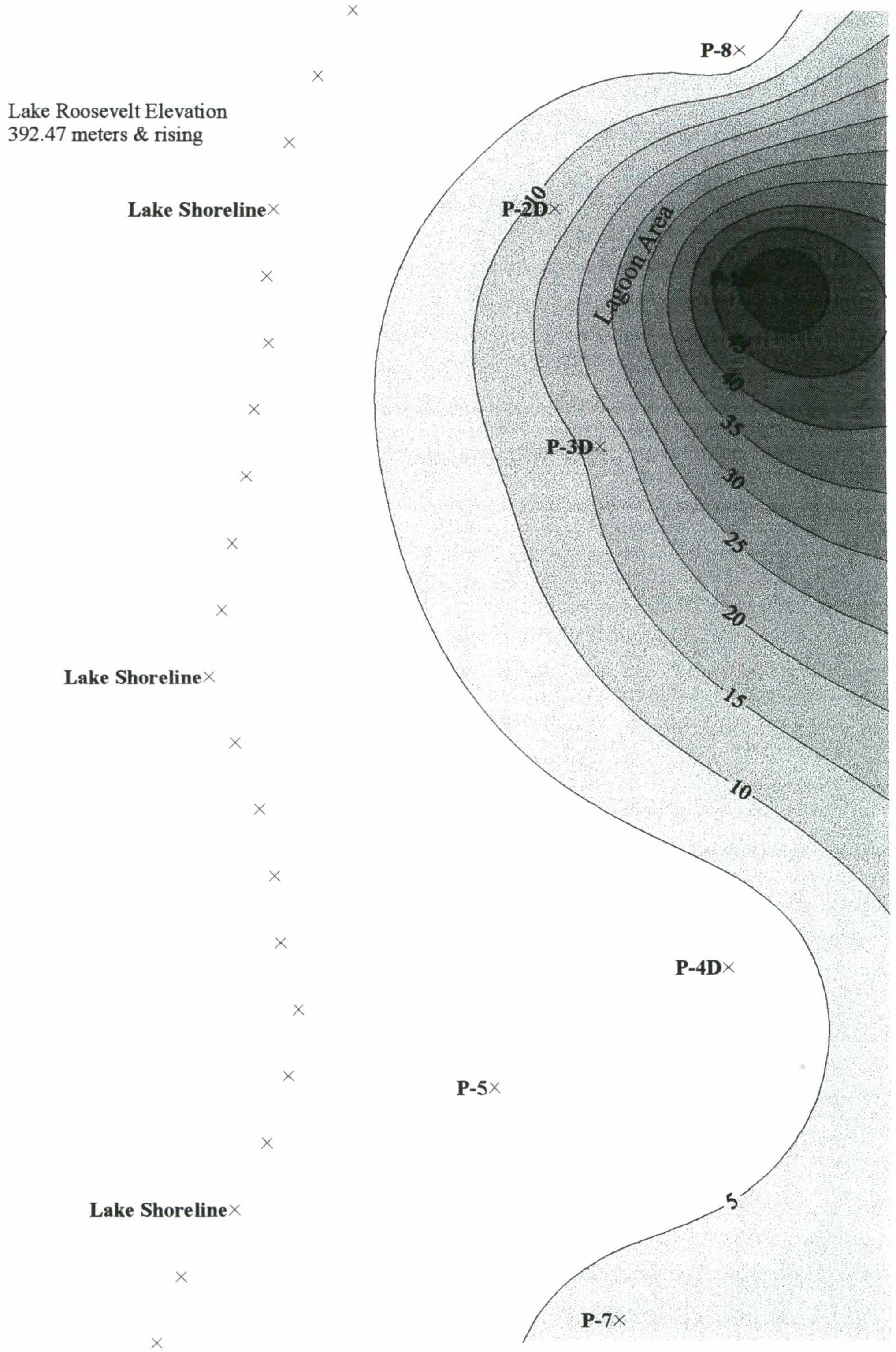


Chemical Oxygen Demand in Groundwater (mg/L) - 9/7/95

Contour Interval = 5 meters

meters

0 50 100 150 200

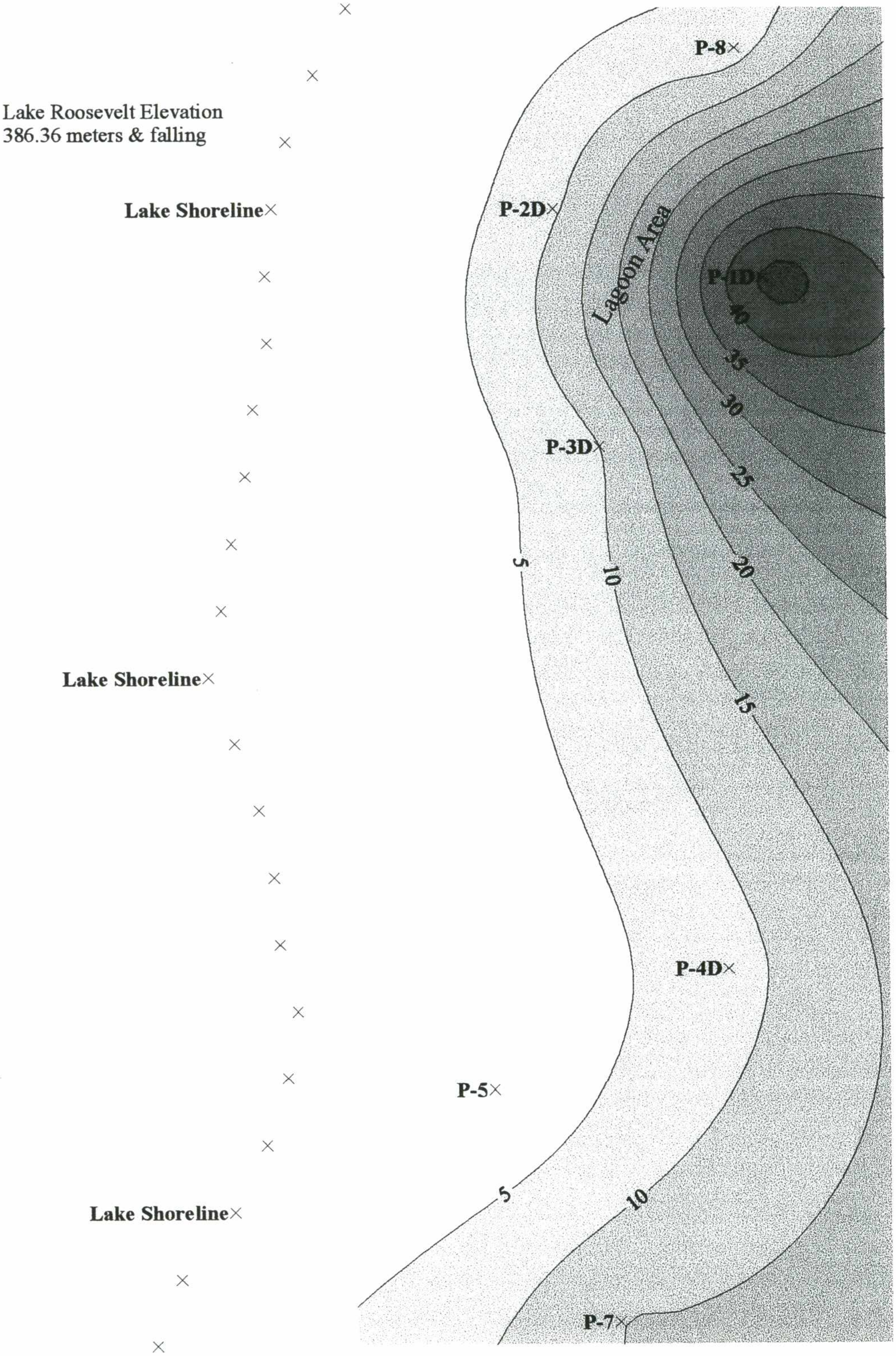


Chemical Oxygen Demand in Groundwater (mg/L) - 12/5/95

Contour Interval = 5 meters

meters

0 50 100 150 200

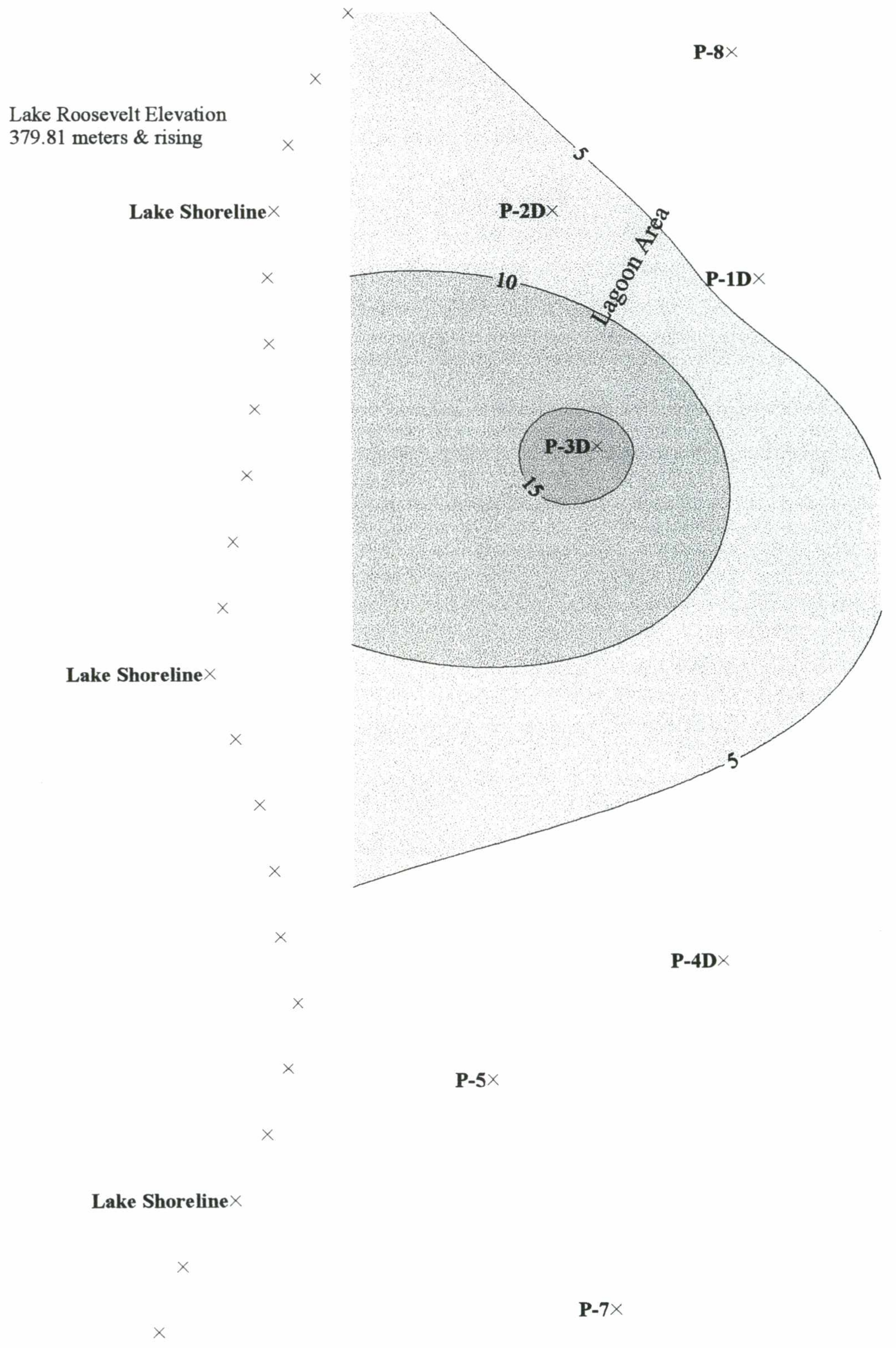


Chemical Oxygen Demand in Groundwater (mg/L) - 3/6/96

Contour Interval = 5 meters

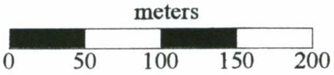
meters

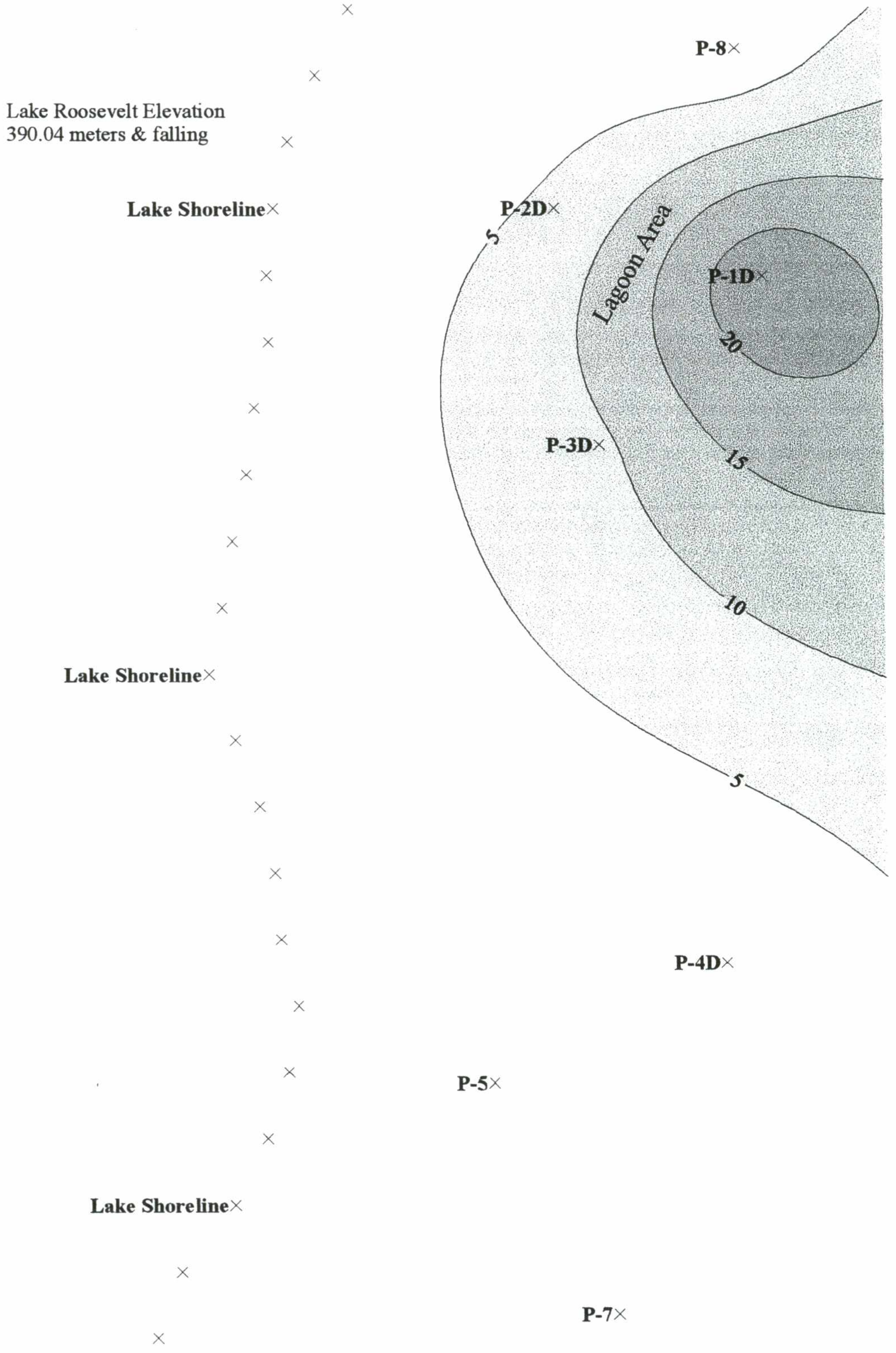
0 50 100 150 200



Chemical Oxygen Demand in Groundwater (mg/L) - 6/7/96

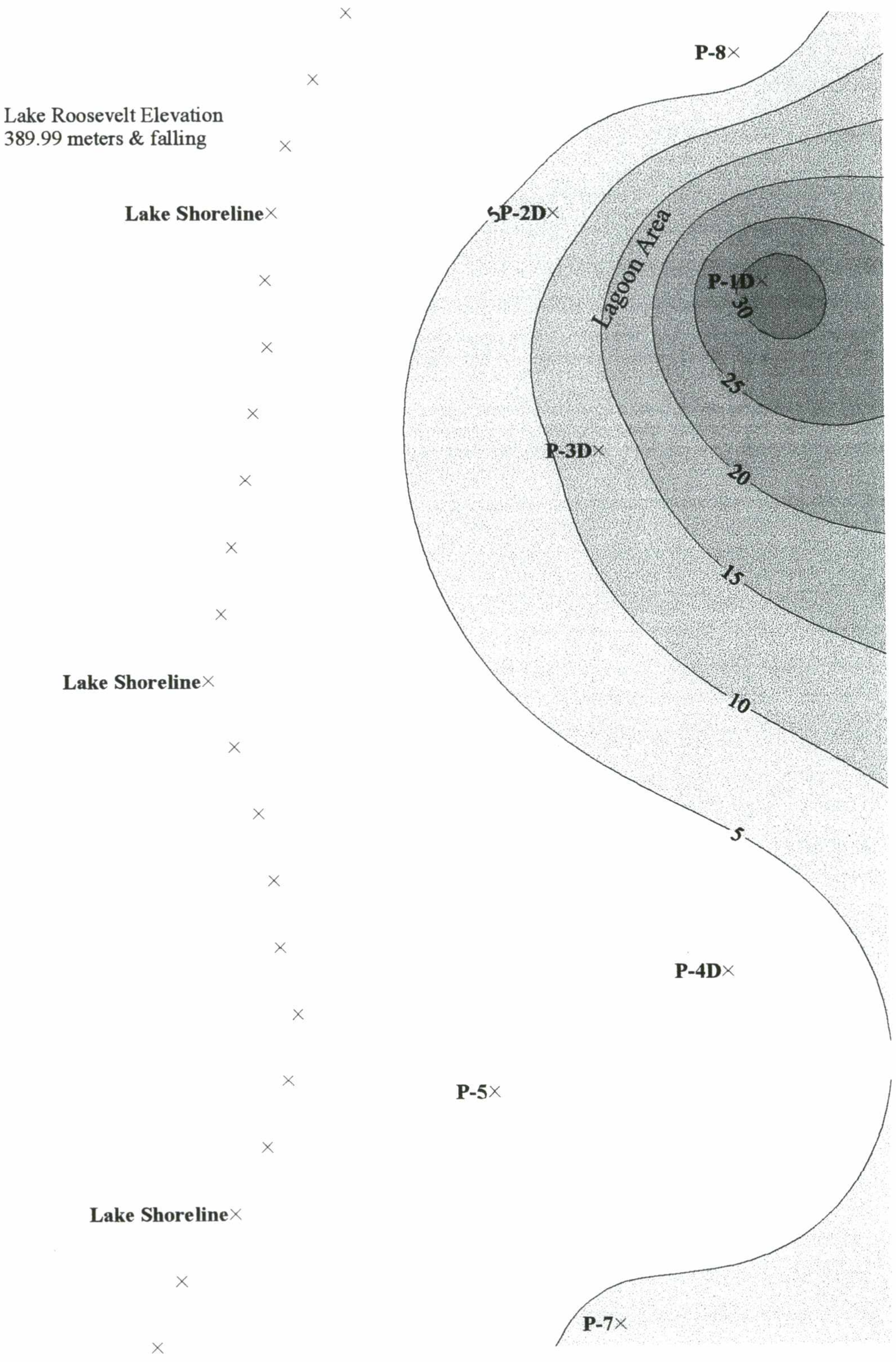
Contour Interval = 5 meters





Chemical Oxygen Demand in Groundwater (mg/L) - 9/12/96

Contour Interval = 5 meters



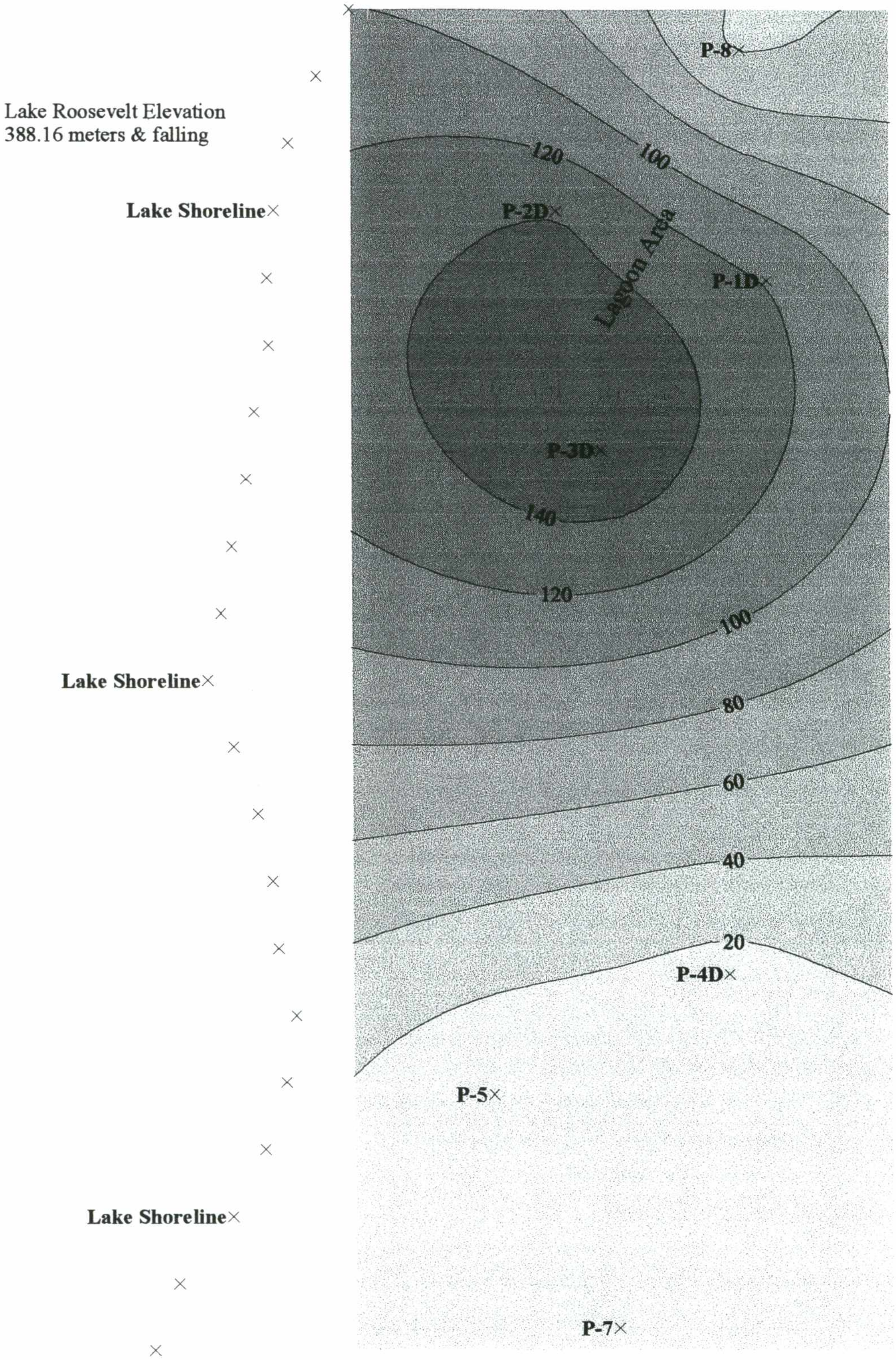
Chemical Oxygen Demand in Groundwater (mg/L) - 12/11/96

Contour Interval = 5 meters

meters

0 50 100 150 200

Chloride in Groundwater -- Contour Maps

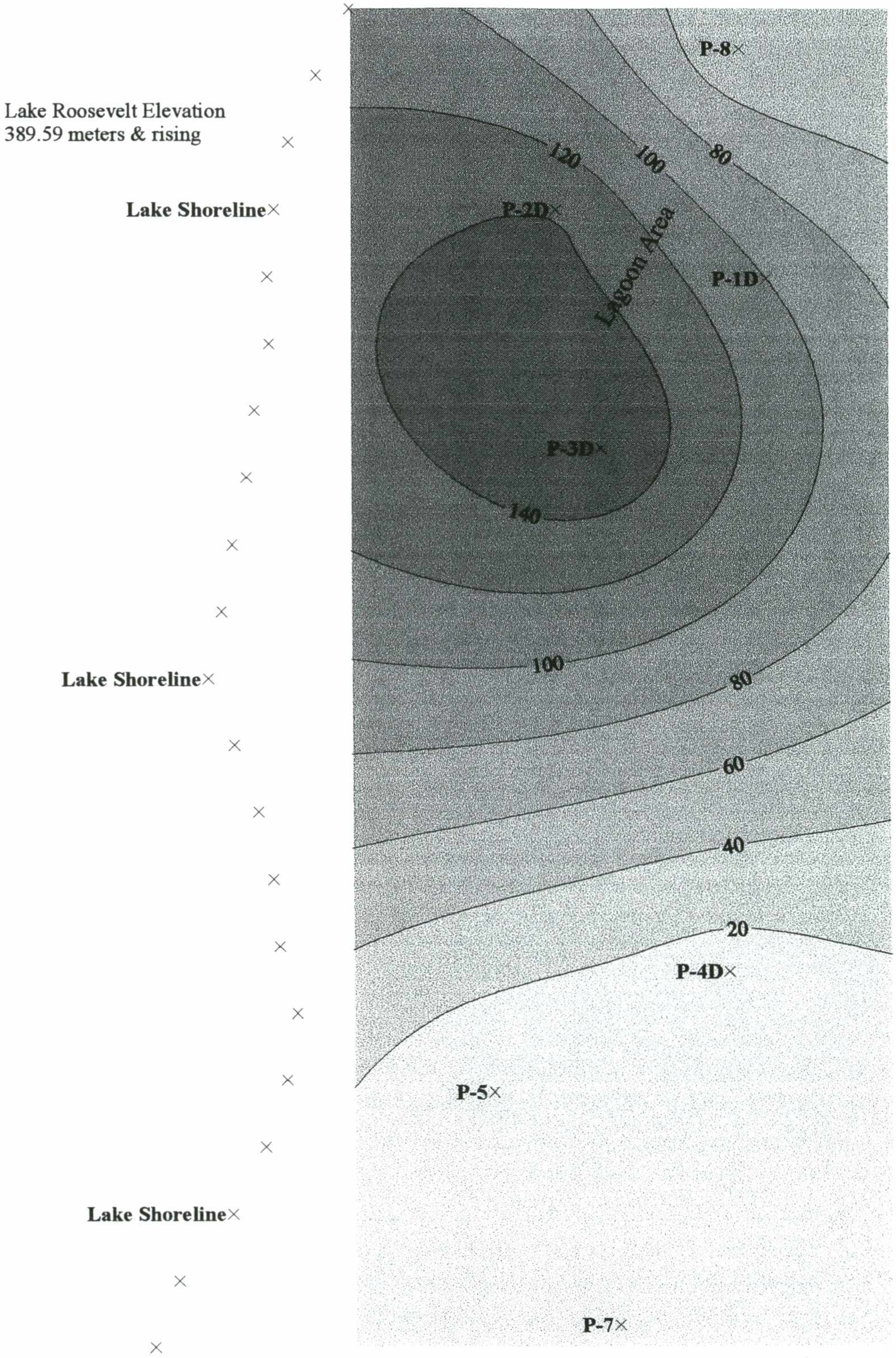


Chloride in Groundwater (mg/L) - 6/21/94

Contour Interval = 20 meters

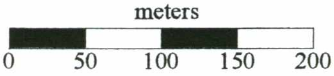
meters

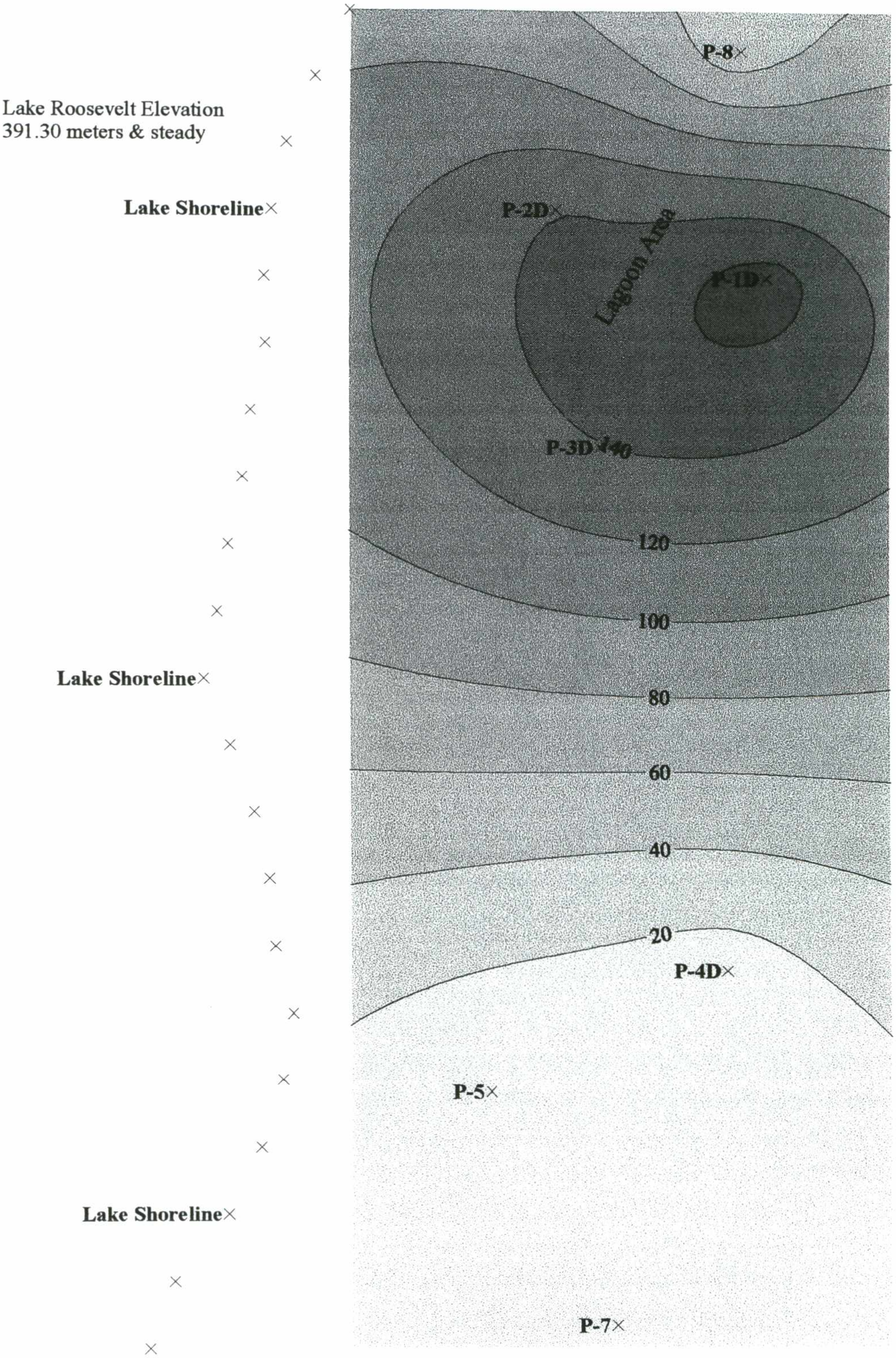
0 50 100 150 200



Chloride in Groundwater (mg/L) - 9/7/94

Contour Interval = 20 meters



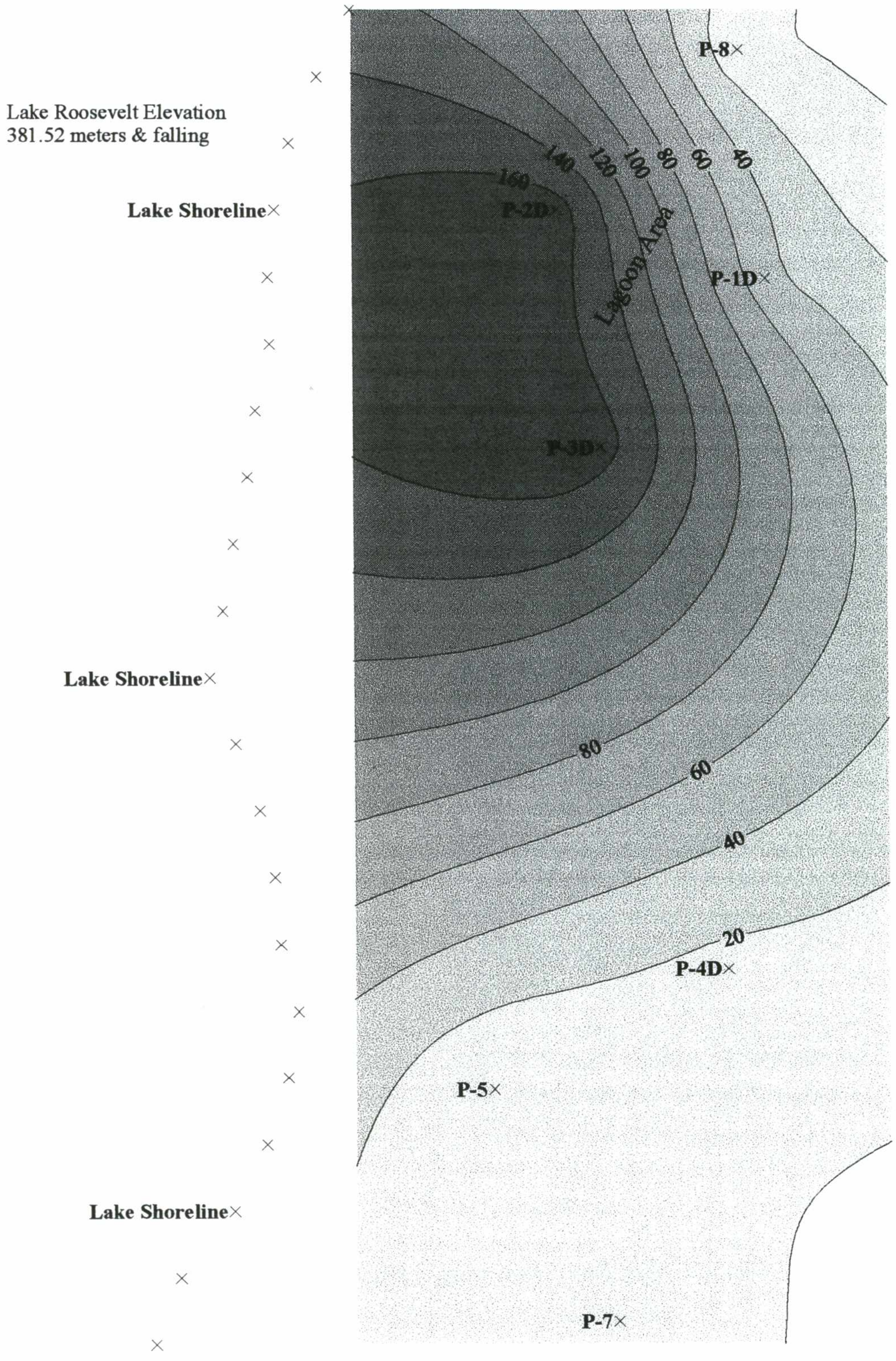


Chloride in Groundwater (mg/L) - 12/5/94

Contour Interval = 20 meters

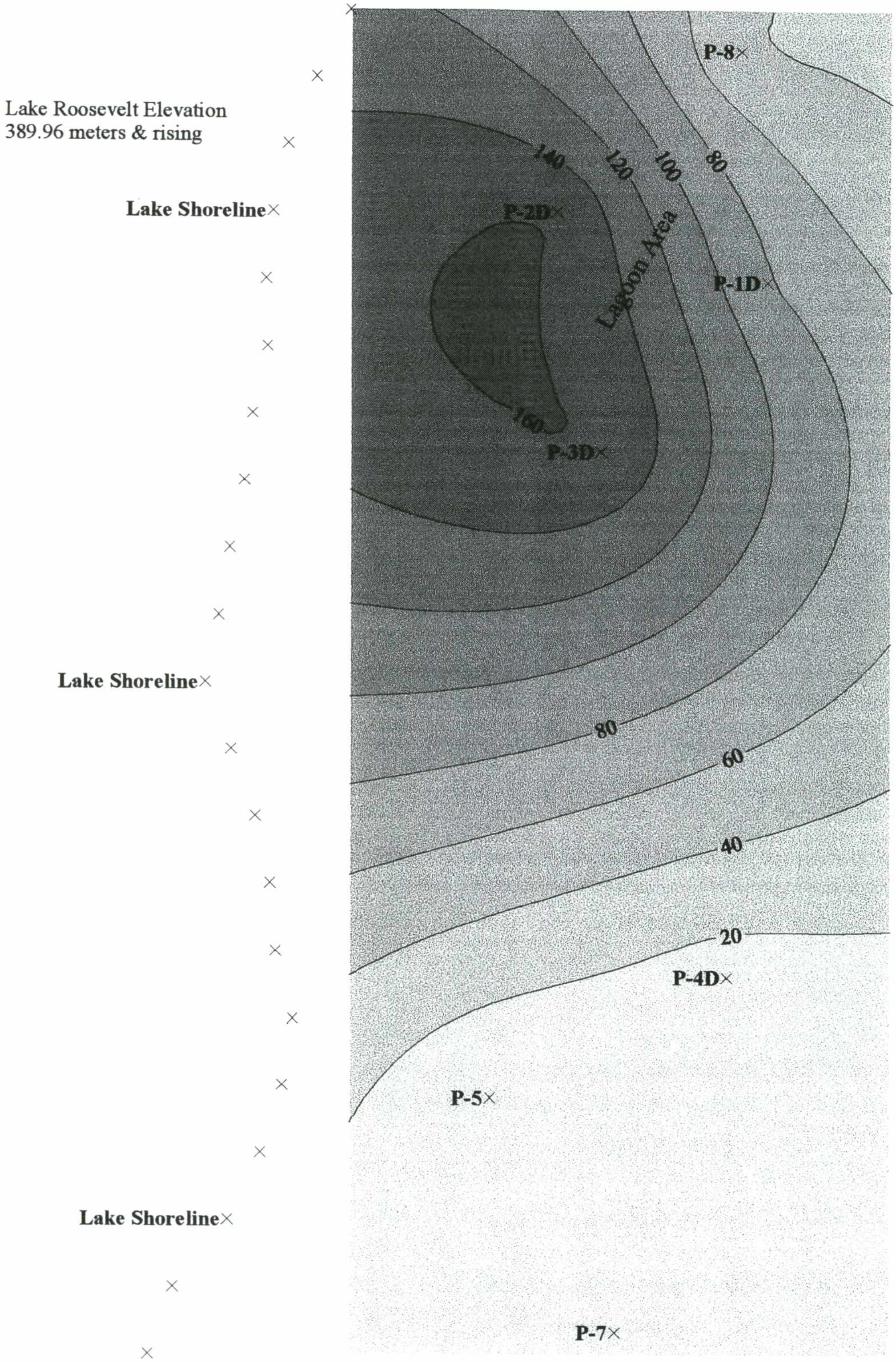
meters

0 50 100 150 200



Chloride in Groundwater (mg/L) - 3/9/95

Contour Interval = 20 meters

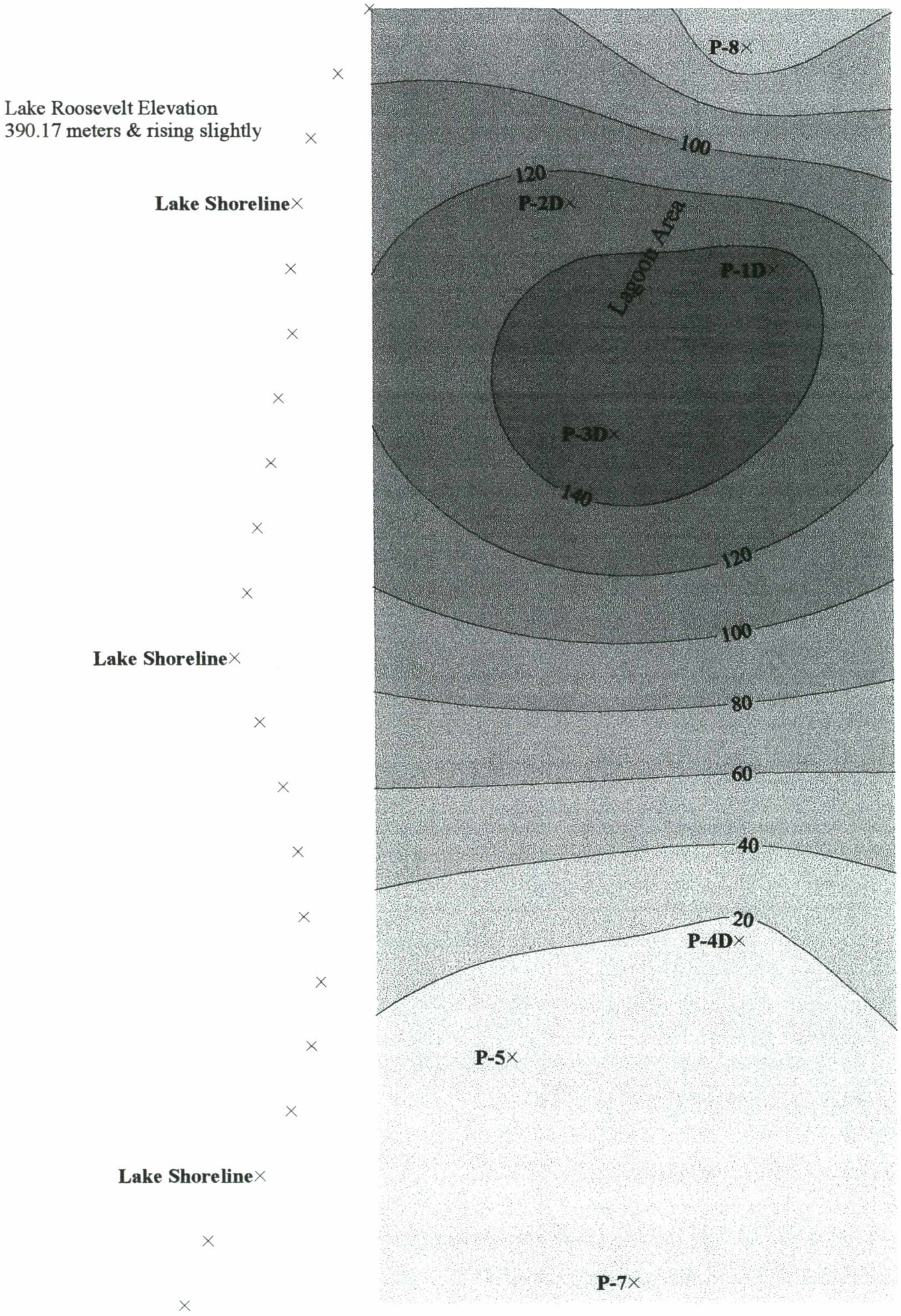


Chloride in Groundwater (mg/L) - 6/8/95

Contour Interval = 20 meters

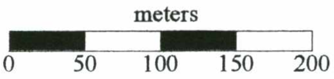
meters

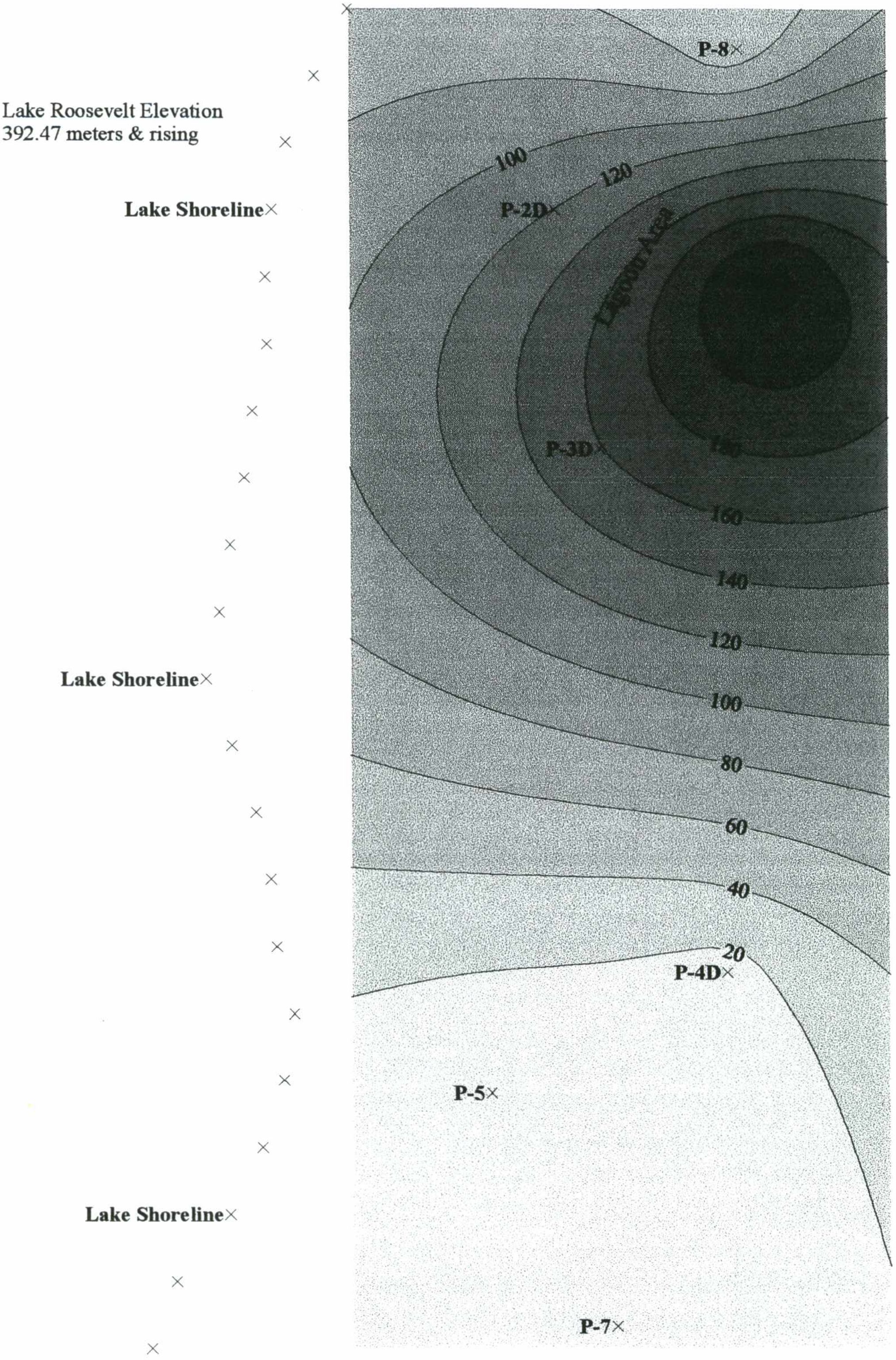
0 50 100 150 200



Chloride in Groundwater (mg/L) - 9/7/95

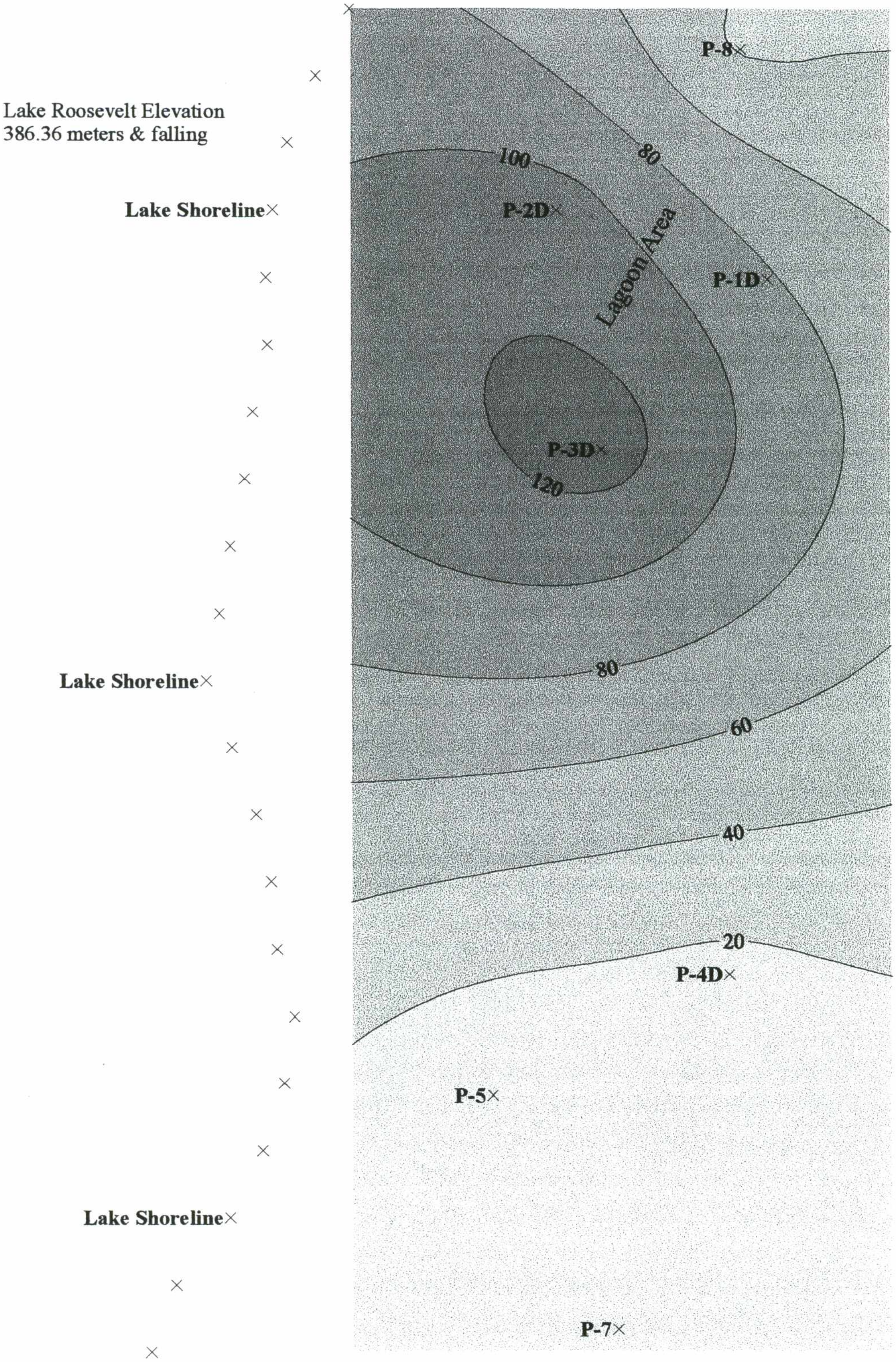
Contour Interval = 20 meters





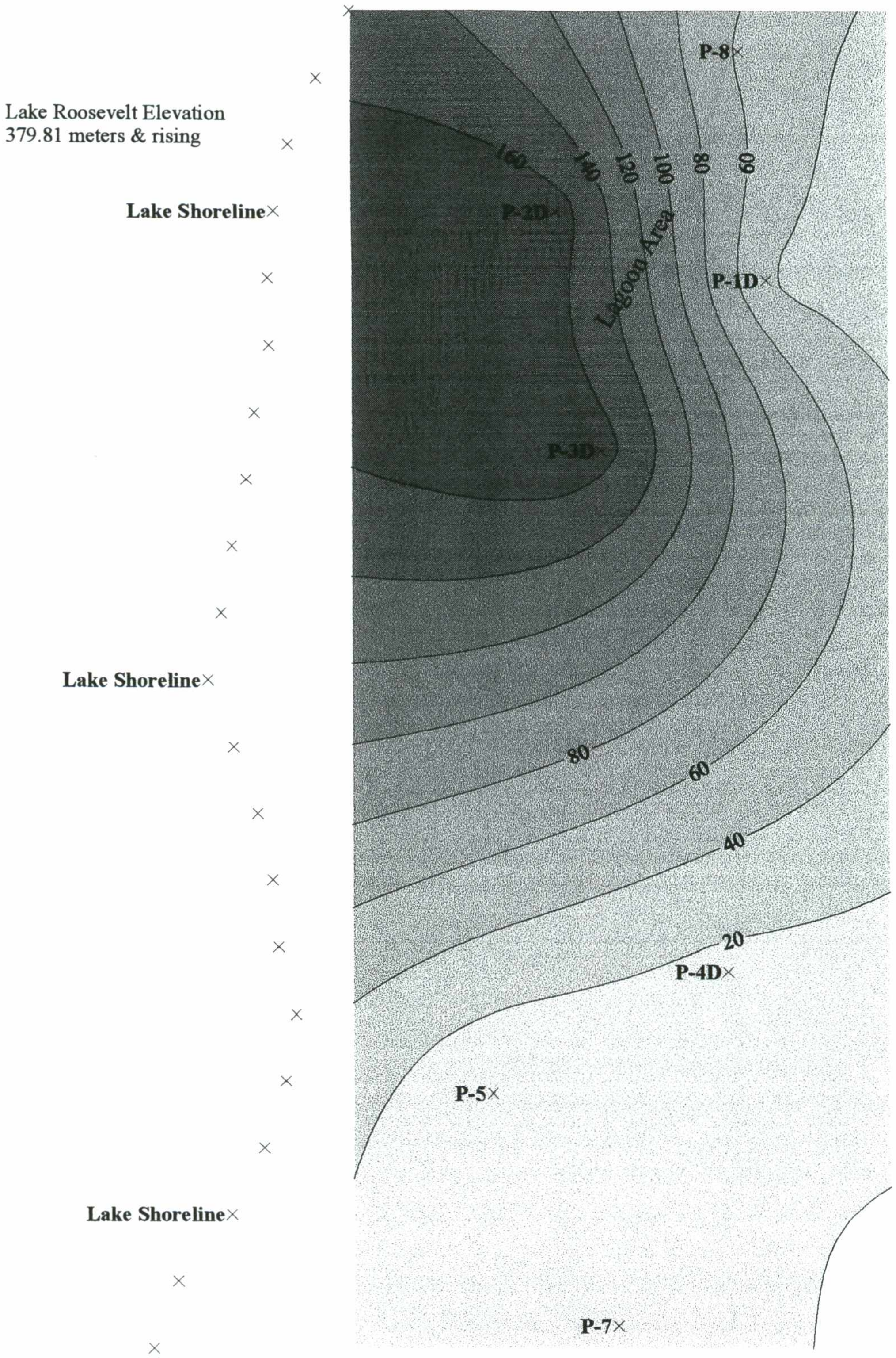
Chloride in Groundwater (mg/L) - 12/5/95

Contour Interval = 20 meters



Chloride in Groundwater (mg/L) - 3/6/96
Contour Interval = 20 meters

meters
0 50 100 150 200

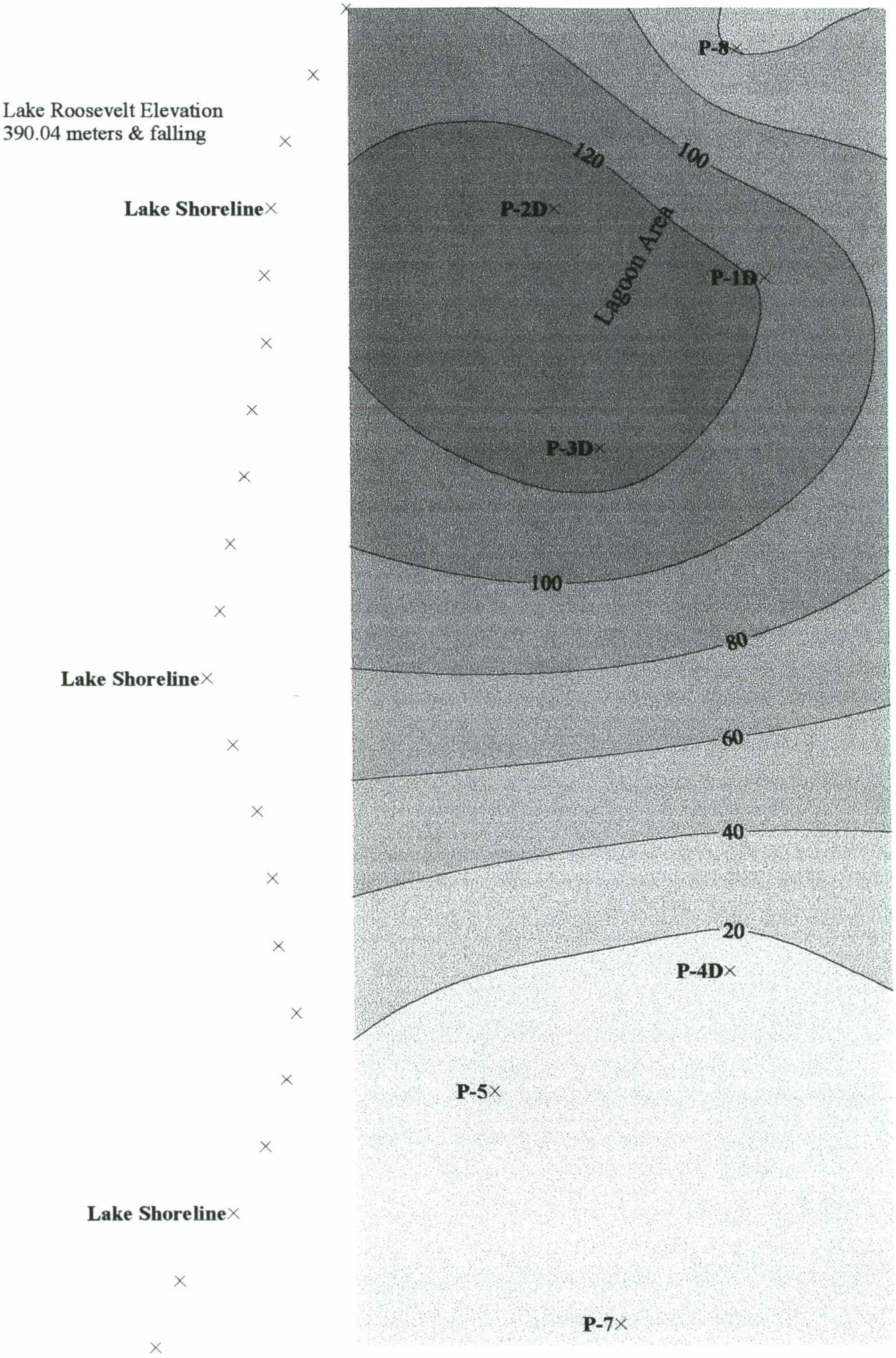


Chloride in Groundwater (mg/L) - 6/7/96

Contour Interval = 20 meters

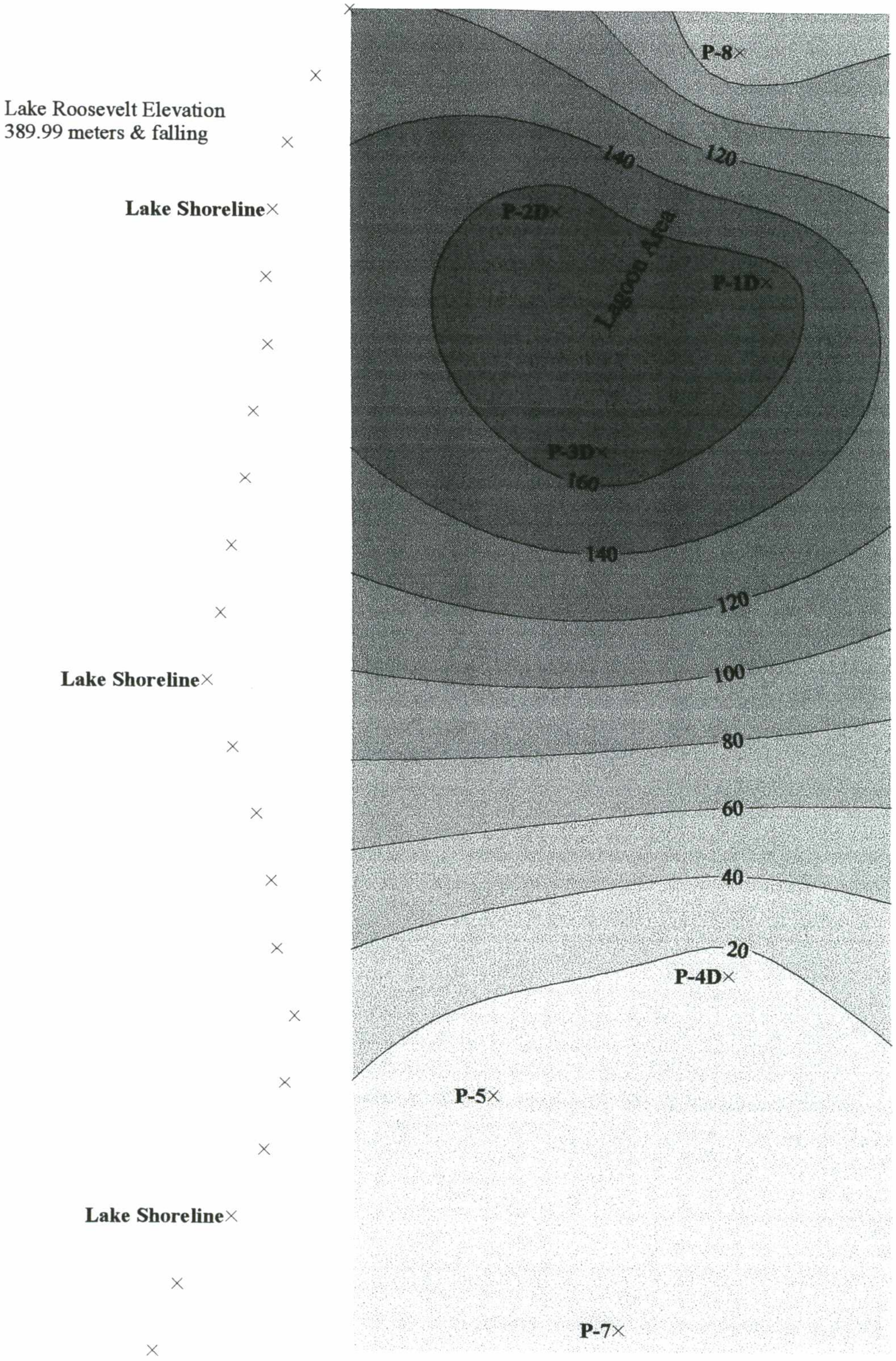
meters

0 50 100 150 200



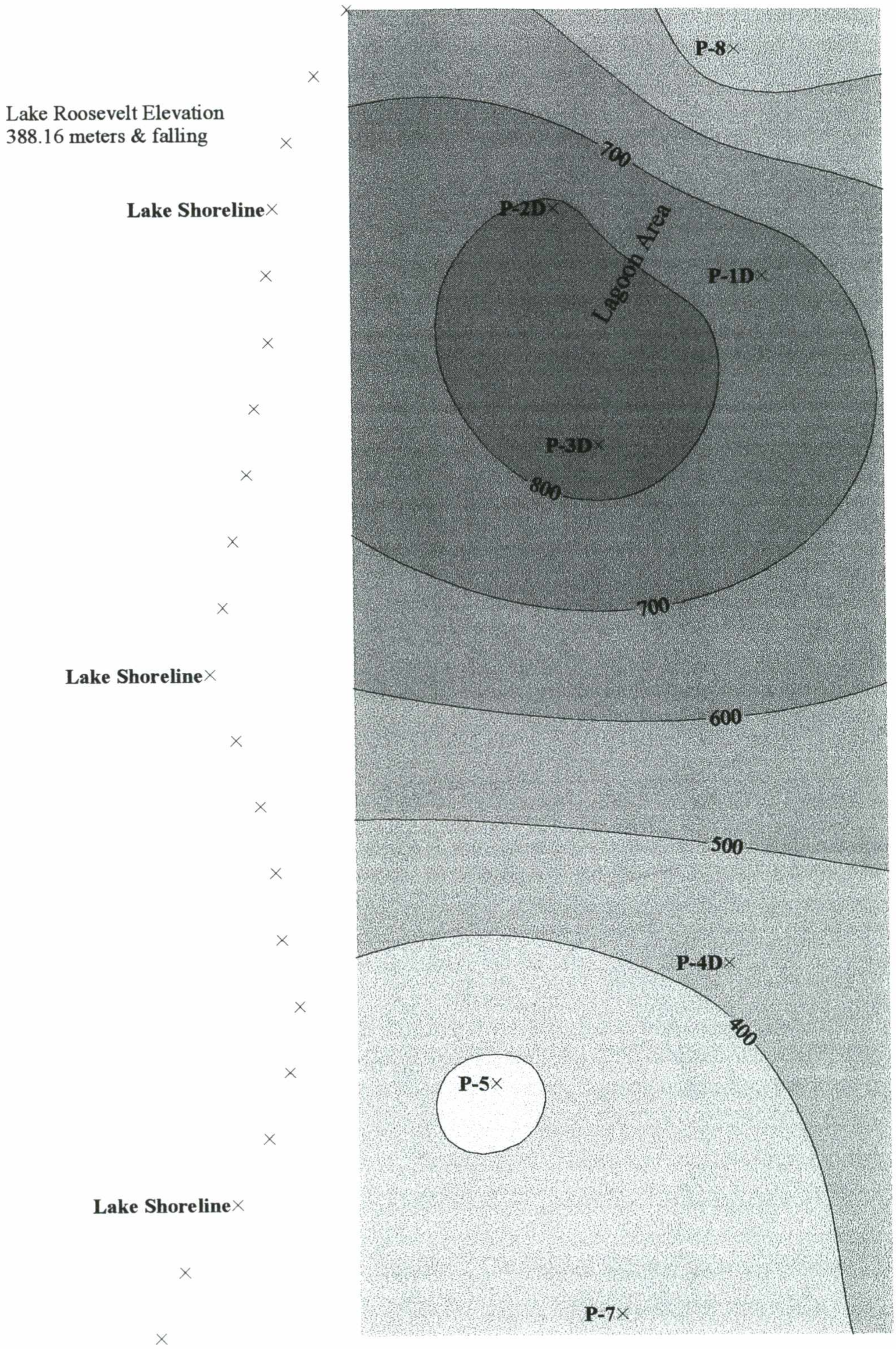
Chloride in Groundwater (mg/L) - 9/12/96

Contour Interval = 20 meters



Chloride in Groundwater (mg/L) - 12/11/96
Contour Interval = 20 meters

Total Dissolved Solids in Groundwater -- Contour Maps

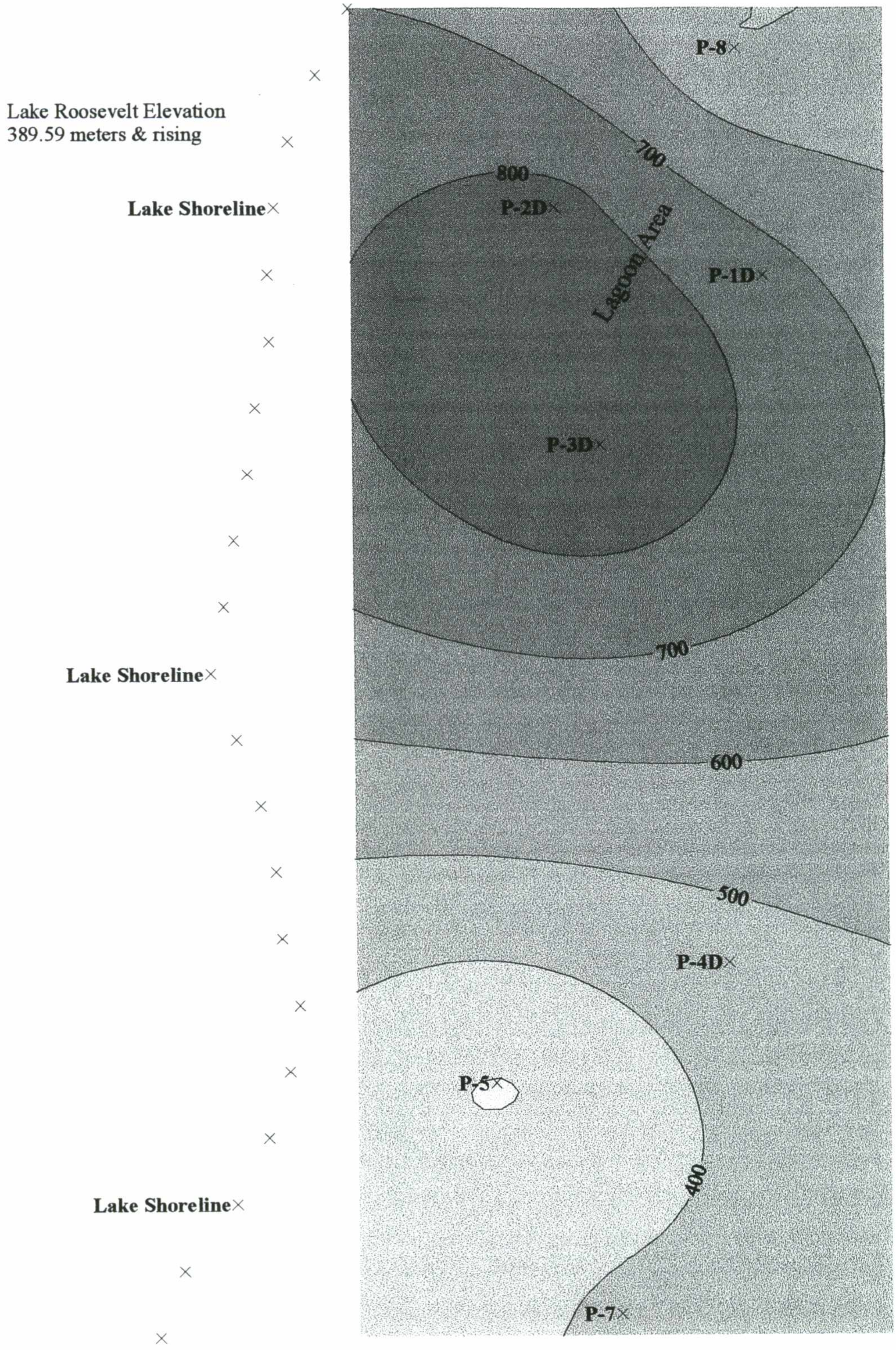


Total Dissolved Solids in Groundwater (mg/L) - 6/21/94

Contour Interval = 100 meters

meters

0 50 100 150 200

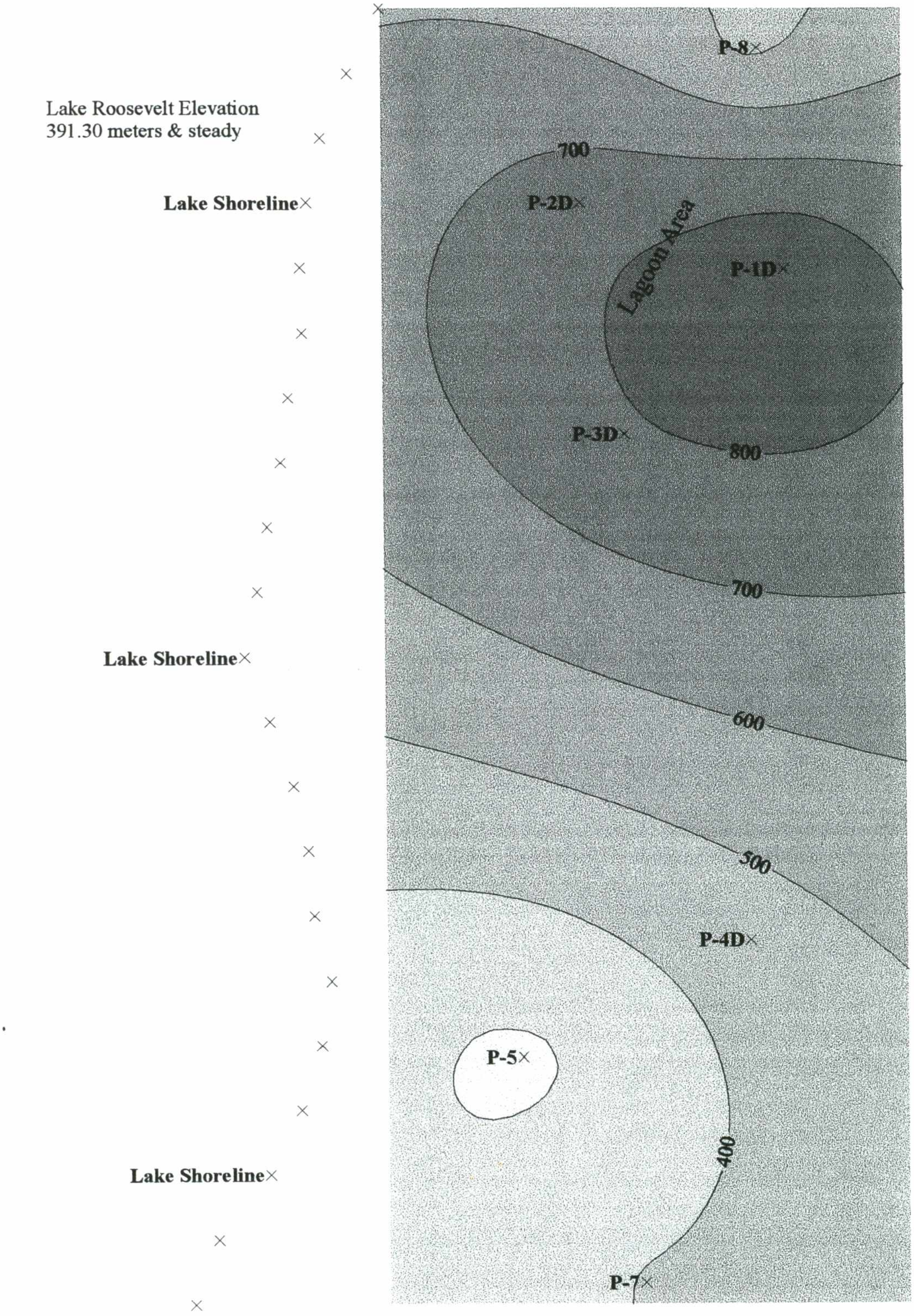


Total Dissolved Solids in Groundwater (mg/L) - 9/7/94

Contour Interval = 100 meters

meters

0 50 100 150 200

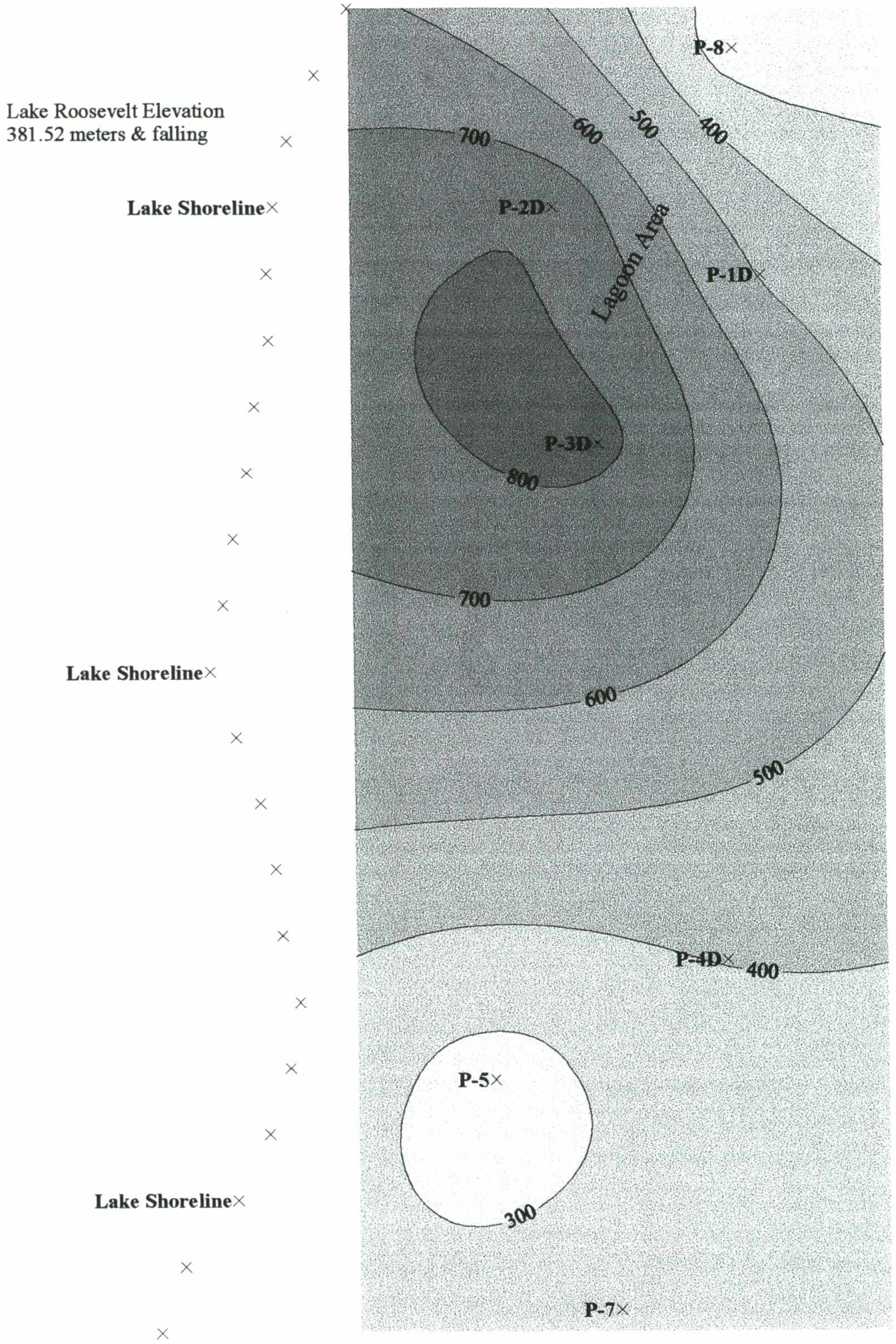


Total Dissolved Solids in Groundwater (mg/L) - 12/5/94

Contour Interval = 100 meters

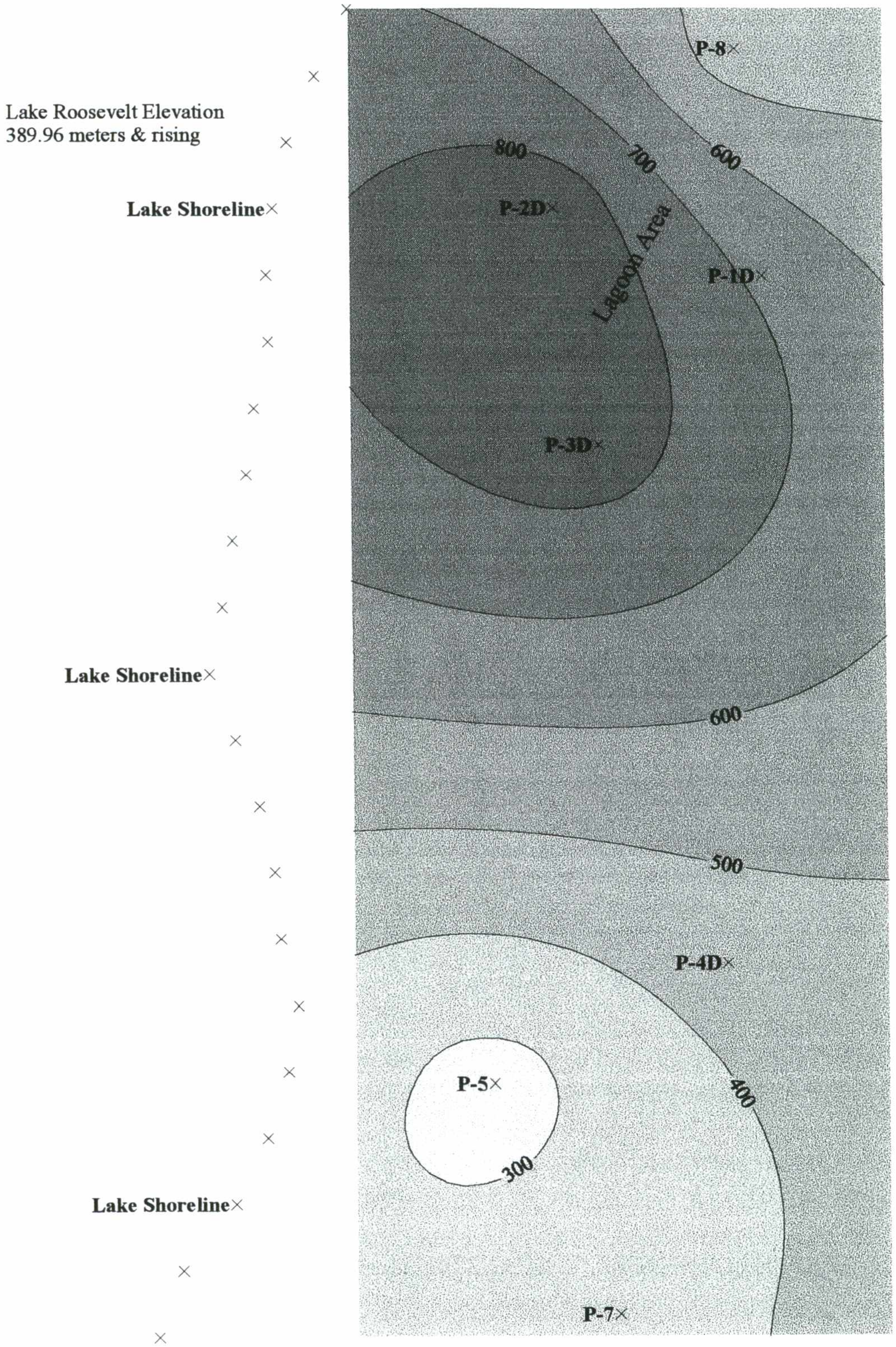
meters

0 50 100 150 200



Total Dissolved Solids in Groundwater (mg/L) - 3/9/95

Contour Interval = 100 meters

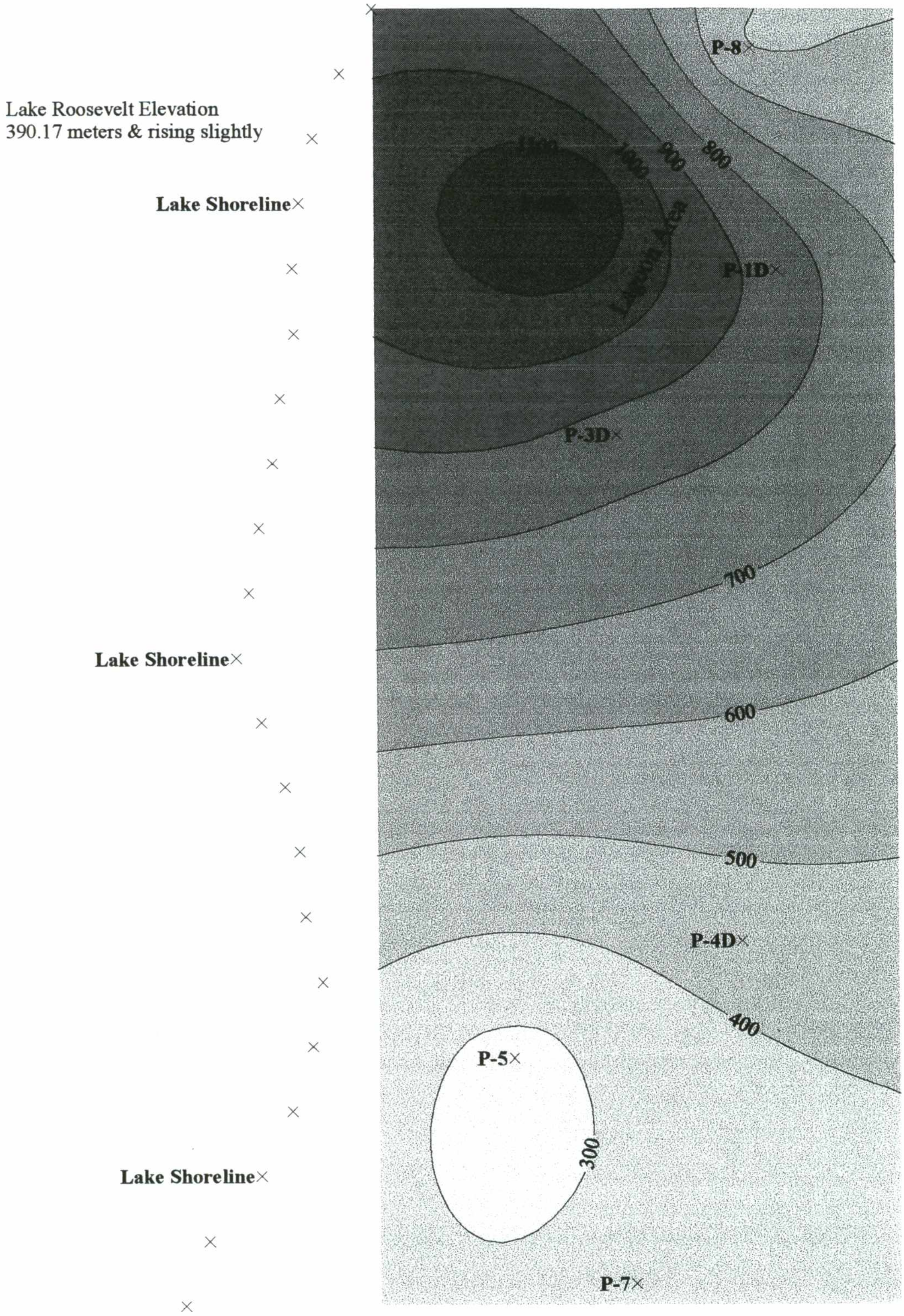


Total Dissolved Solids in Groundwater (mg/L) - 6/8/95

Contour Interval = 100 meters

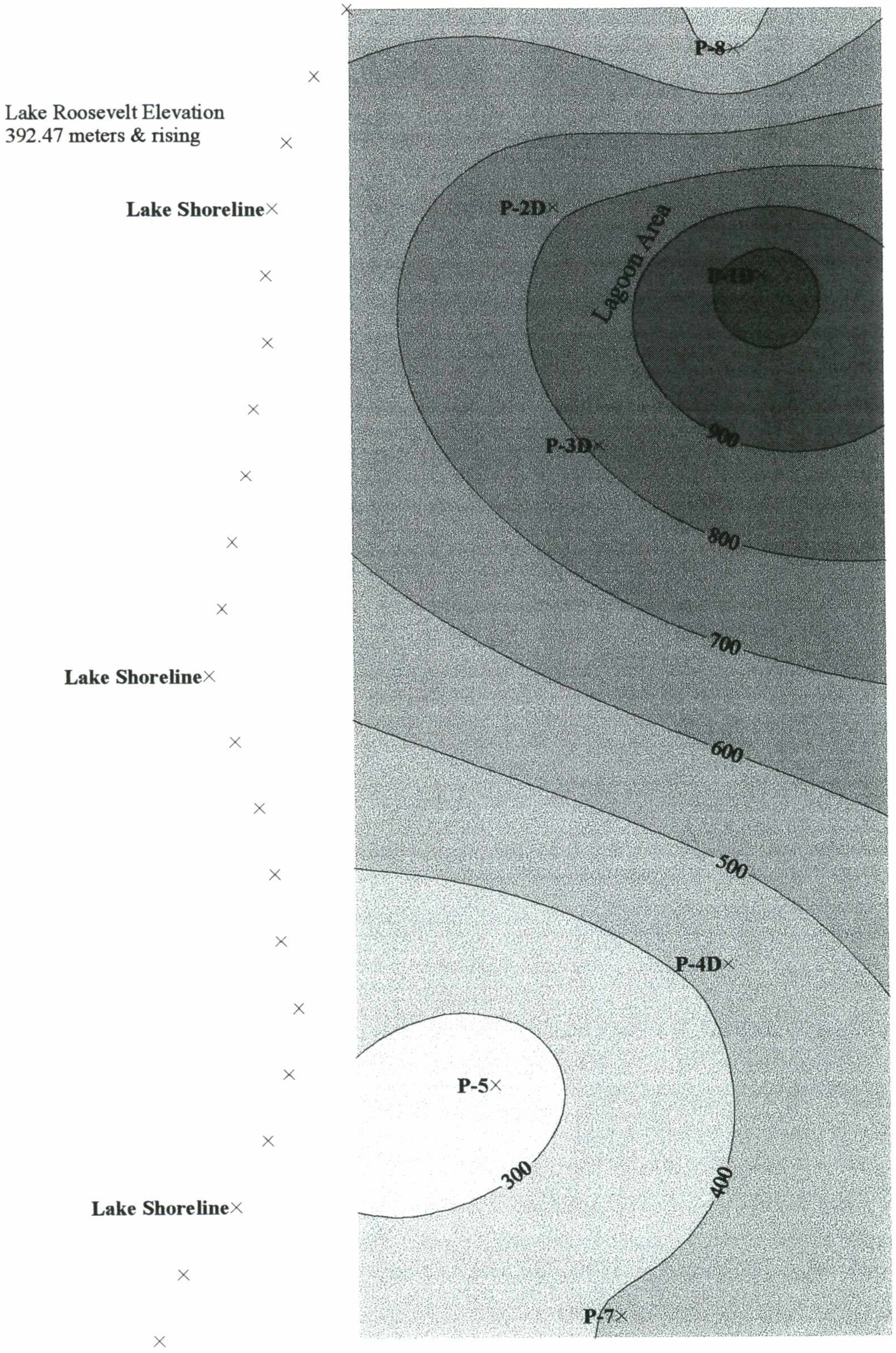
meters

0 50 100 150 200



Total Dissolved Solids in Groundwater (mg/L) - 9/7/95

Contour Interval = 100 meters

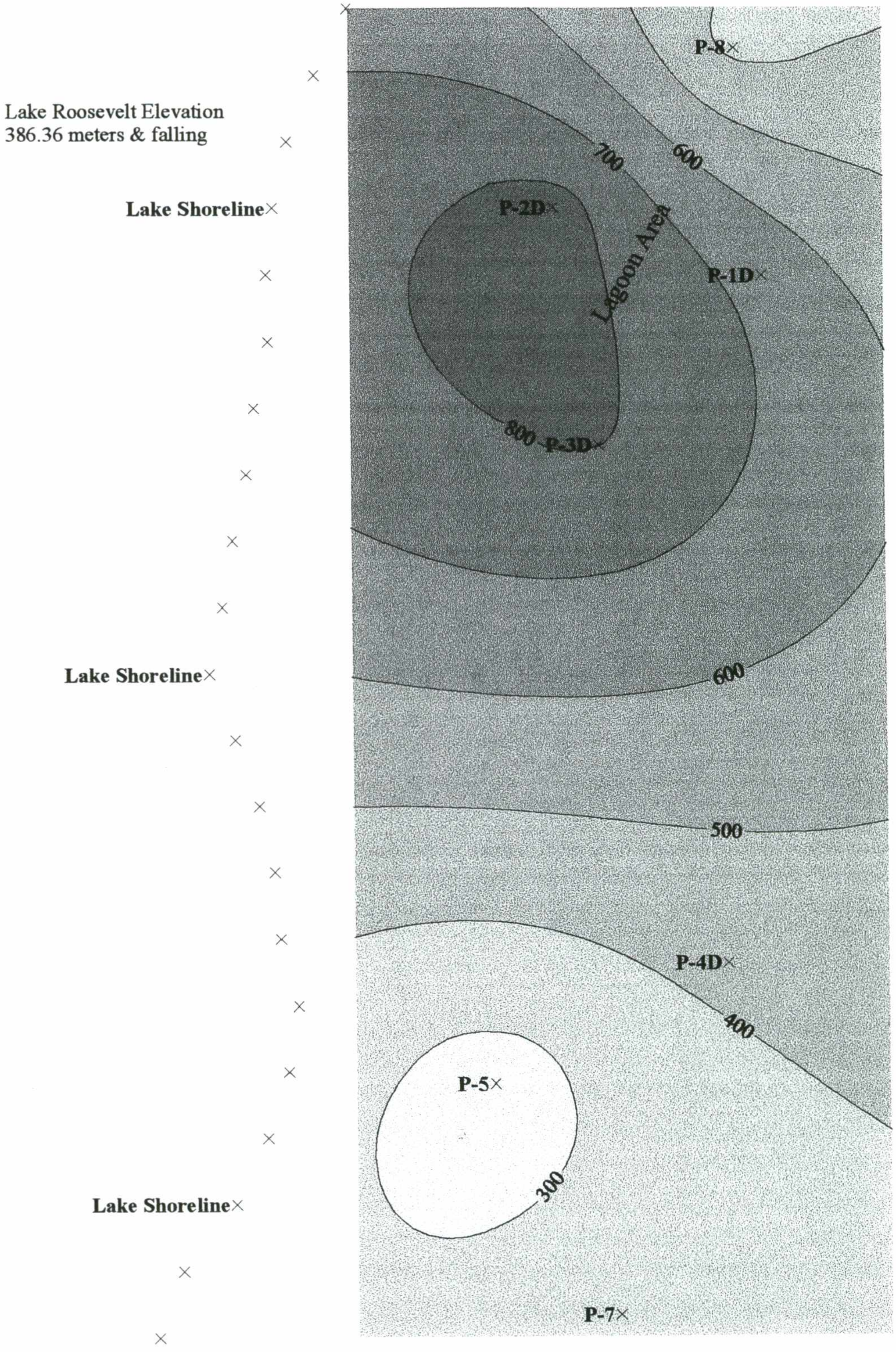


Total Dissolved Solids in Groundwater (mg/L) - 12/5/95

Contour Interval = 100 meters

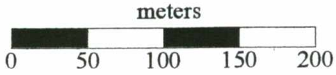
meters

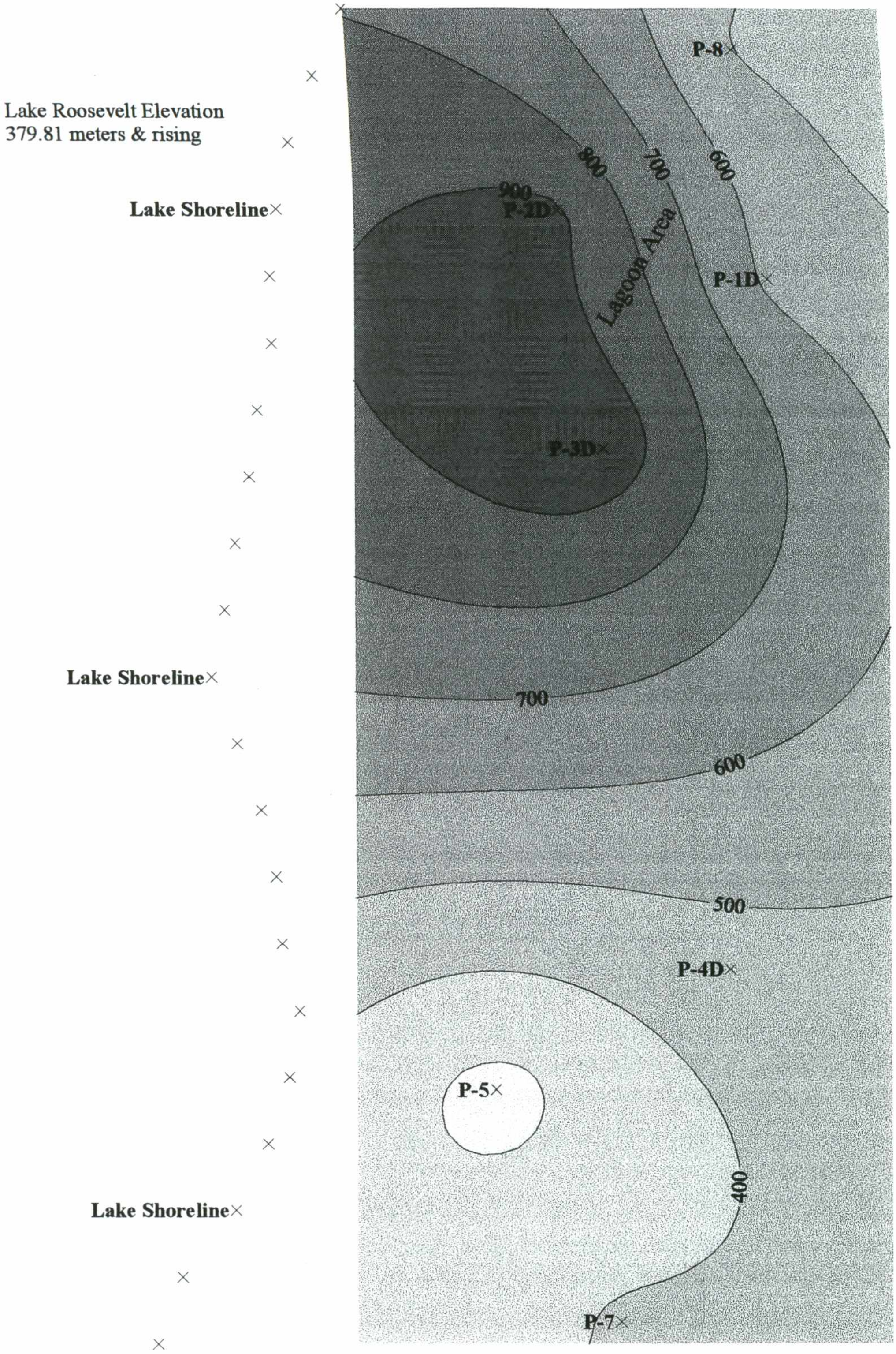
0 50 100 150 200



Total Dissolved Solids in Groundwater (mg/L) - 3/6/96

Contour Interval = 100 meters



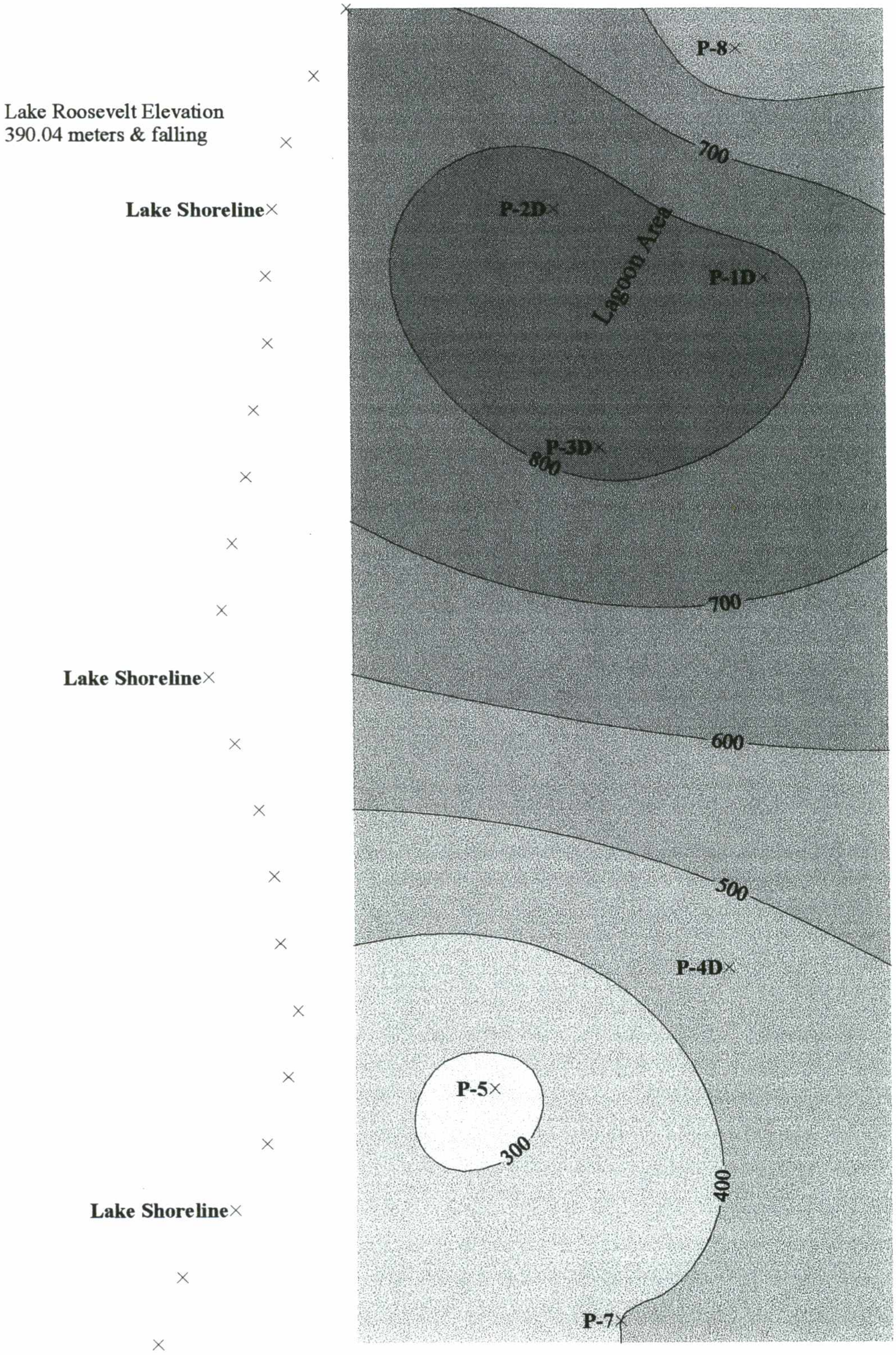


Total Dissolved Solids in Groundwater (mg/L) - 6/7/96

Contour Interval = 100 meters

meters

0 50 100 150 200

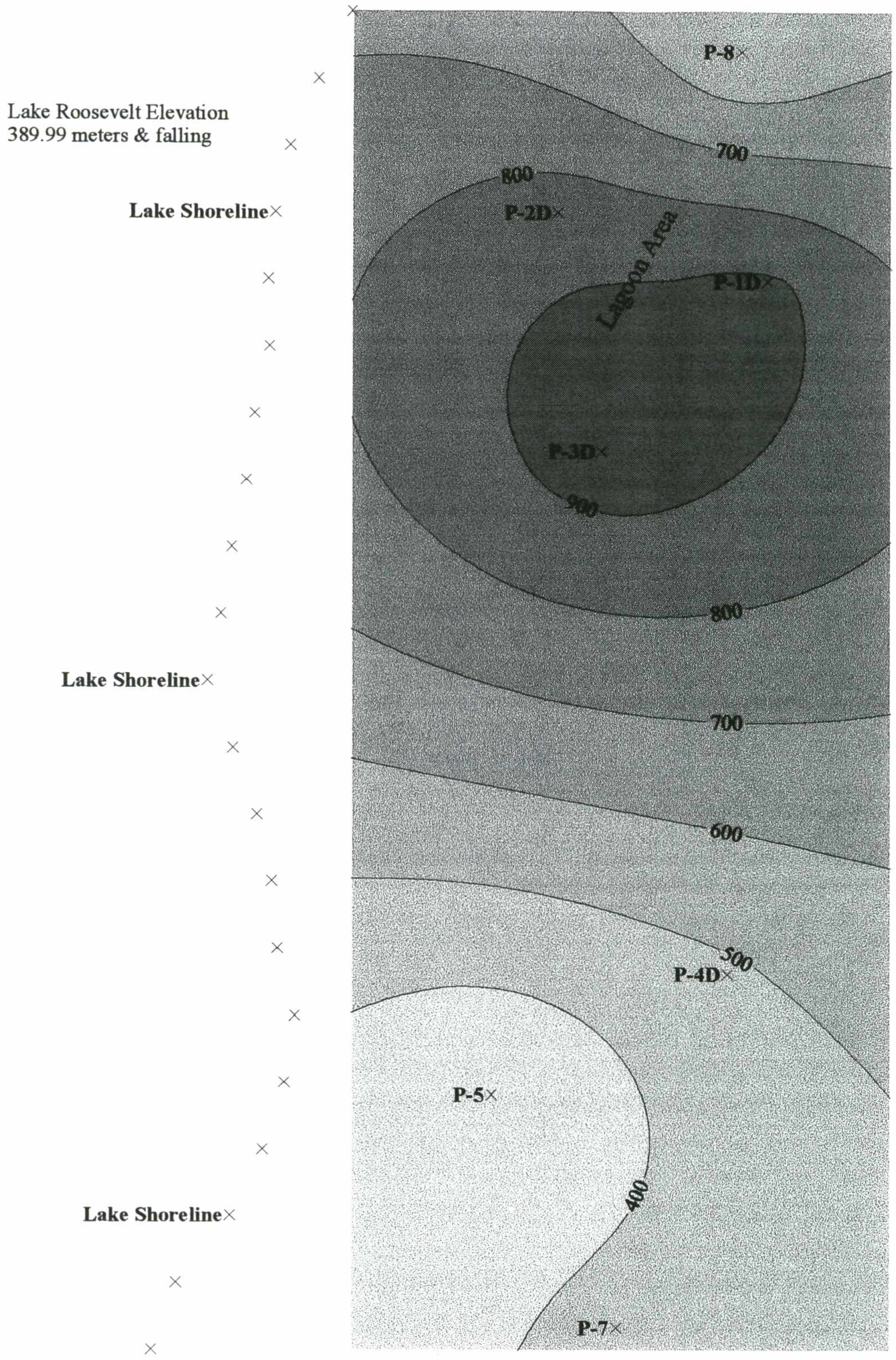


Total Dissolved Solids in Groundwater (mg/L) - 9/12/96

Contour Interval = 100 meters

meters

0 50 100 150 200



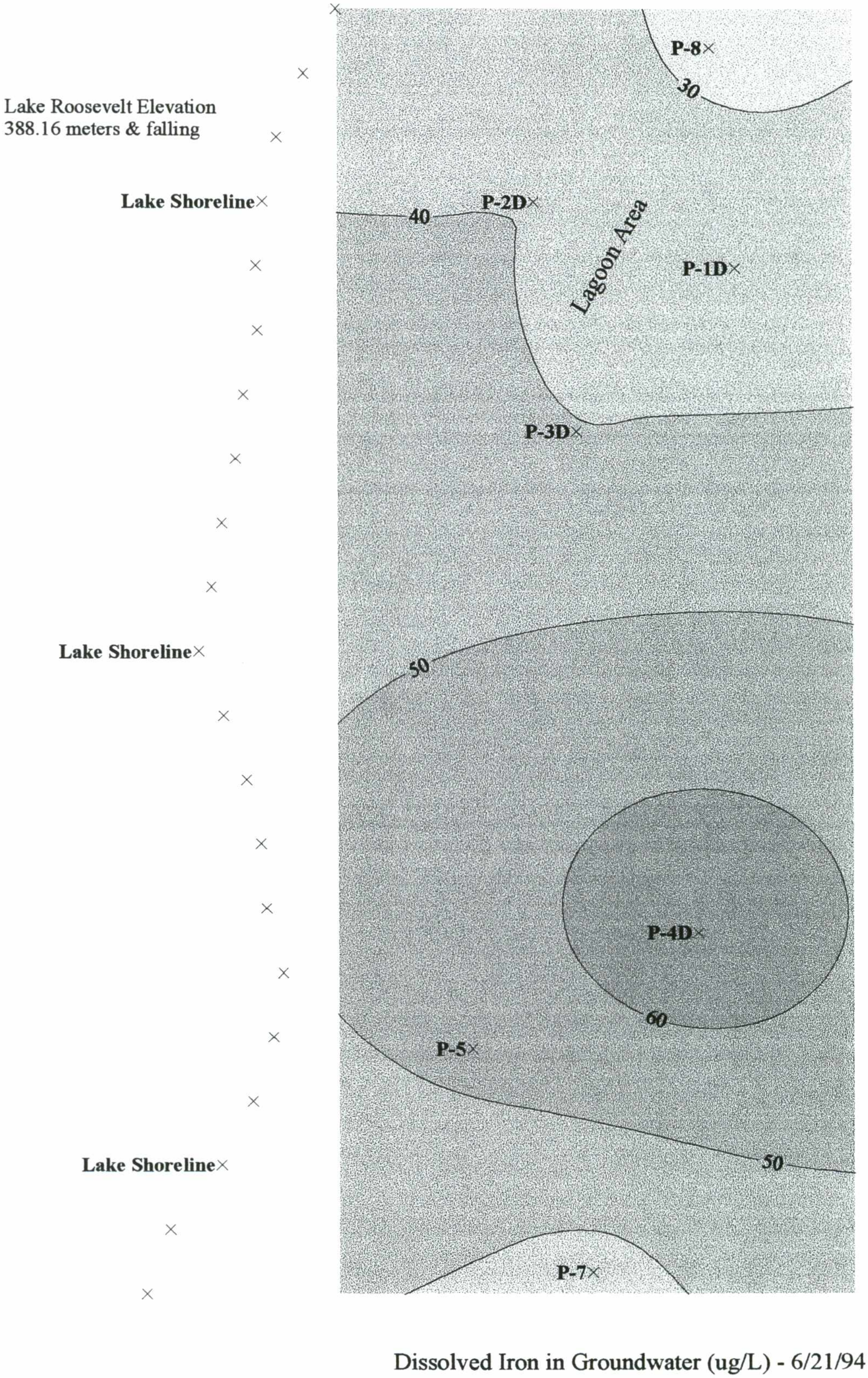
Total Dissolved Solids in Groundwater (mg/L) - 12/11/96

Contour Interval = 100 meters

meters

0 50 100 150 200

Dissolved Iron in Groundwater -- Contour Maps

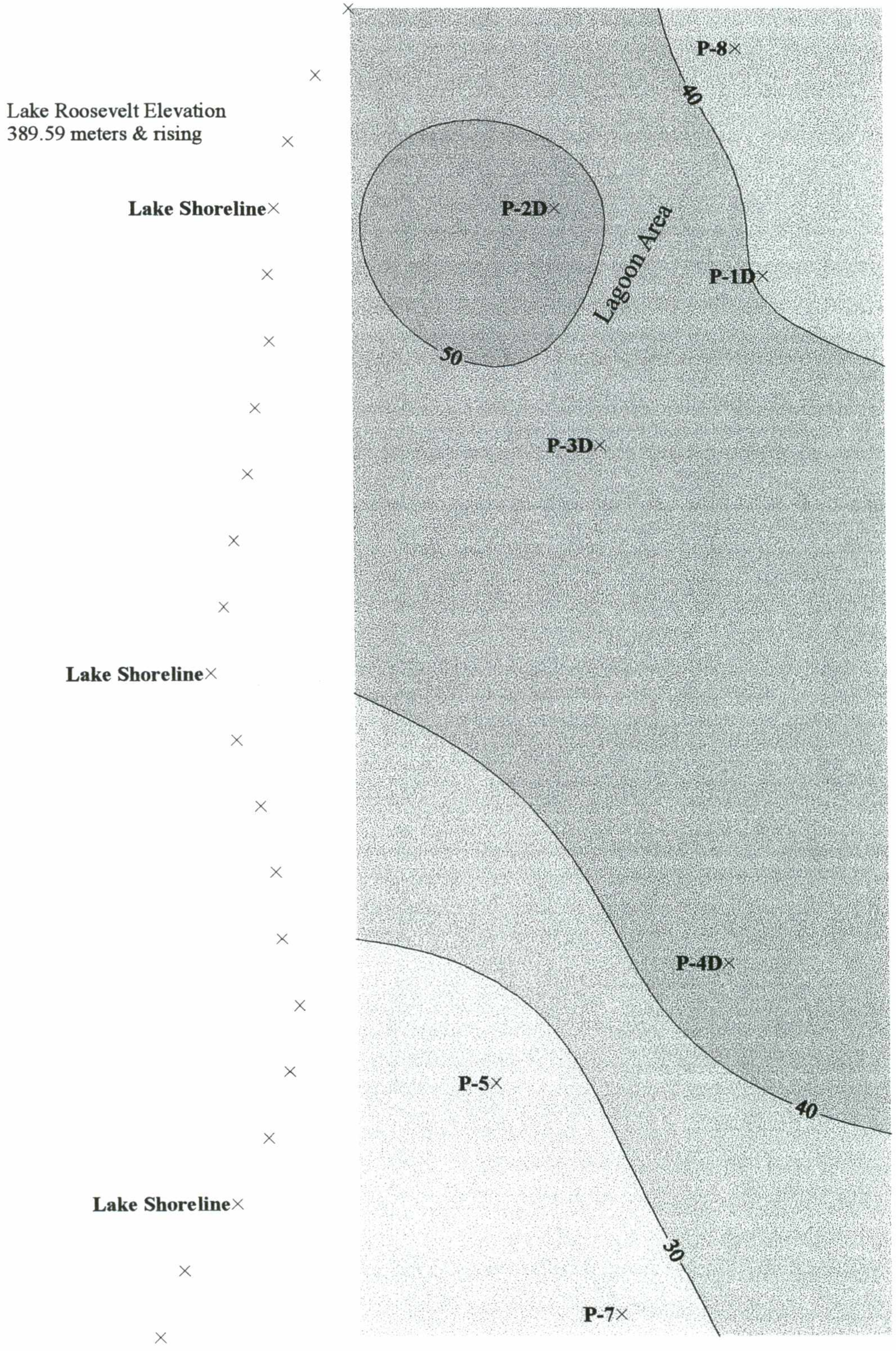


Dissolved Iron in Groundwater (ug/L) - 6/21/94

Contour Interval = 10 meters

meters

0 50 100 150 200

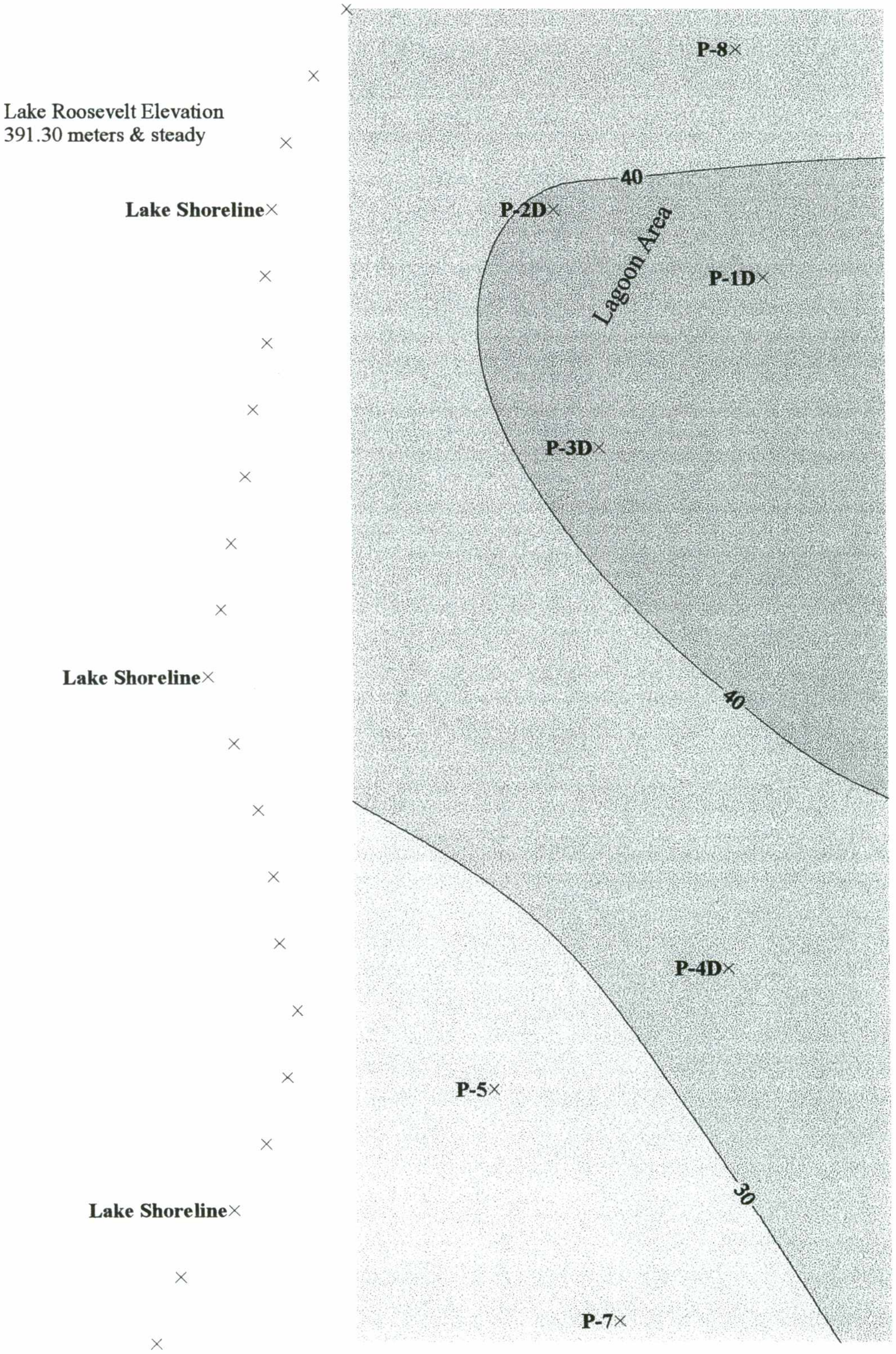


Dissolved Iron in Groundwater (ug/L) - 9/7/94

Contour Interval = 10 meters

meters

0 50 100 150 200

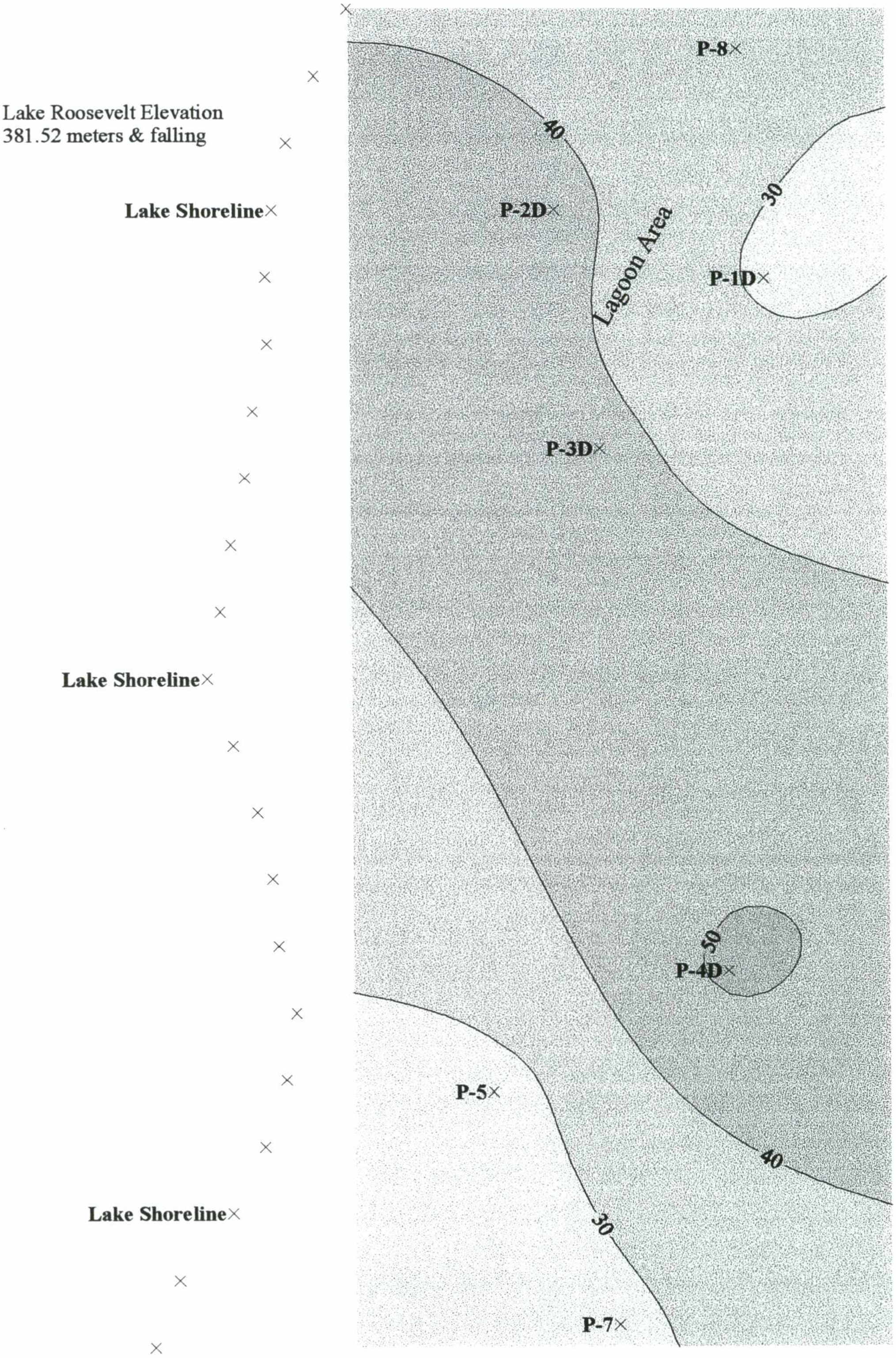


Dissolved Iron in Groundwater (ug/L) - 12/5/94

Contour Interval = 10 meters

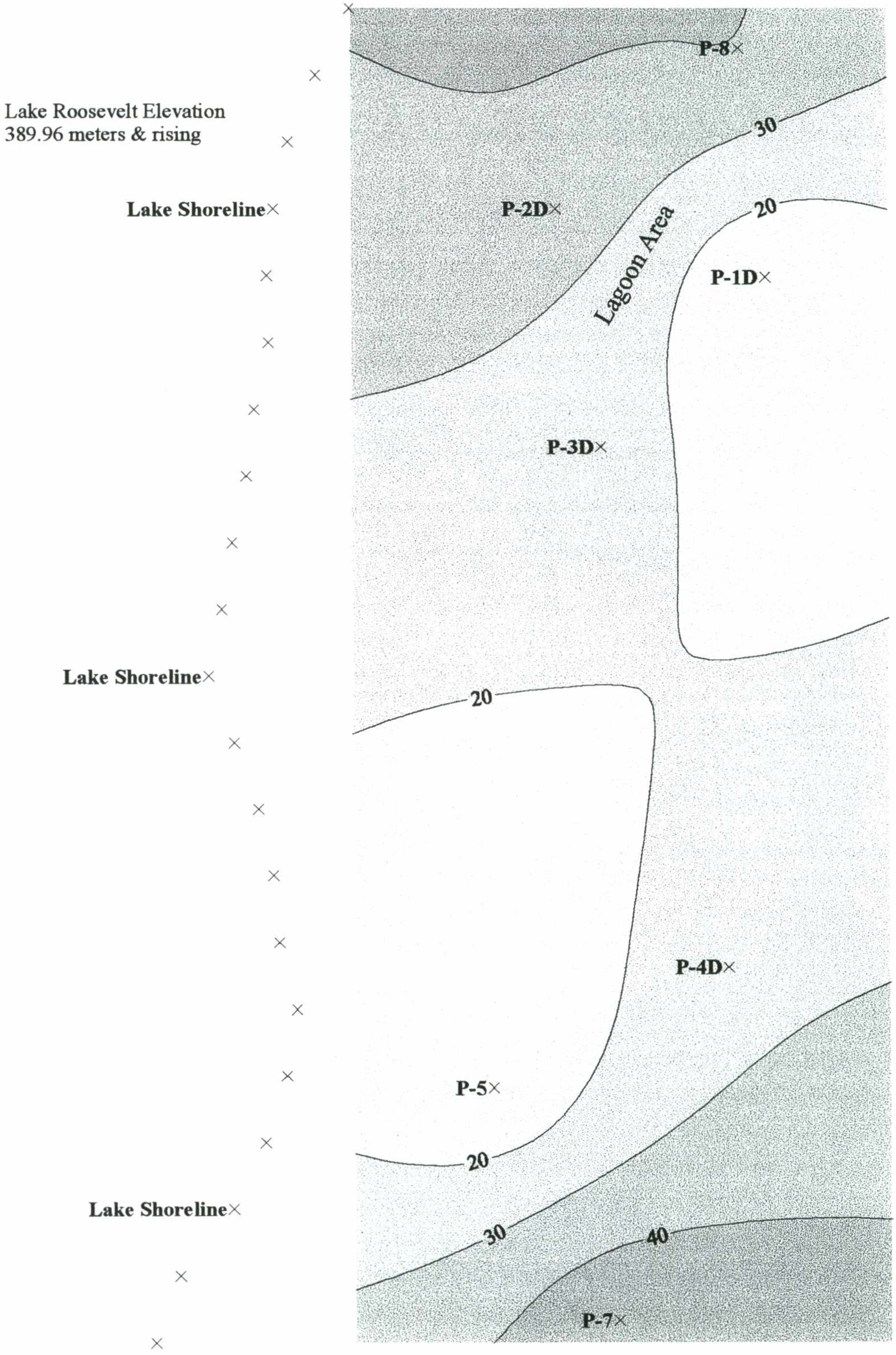
meters

0 50 100 150 200



Dissolved Iron in Groundwater (ug/L) - 3/9/95
Contour Interval = 10 meters

meters
0 50 100 150 200

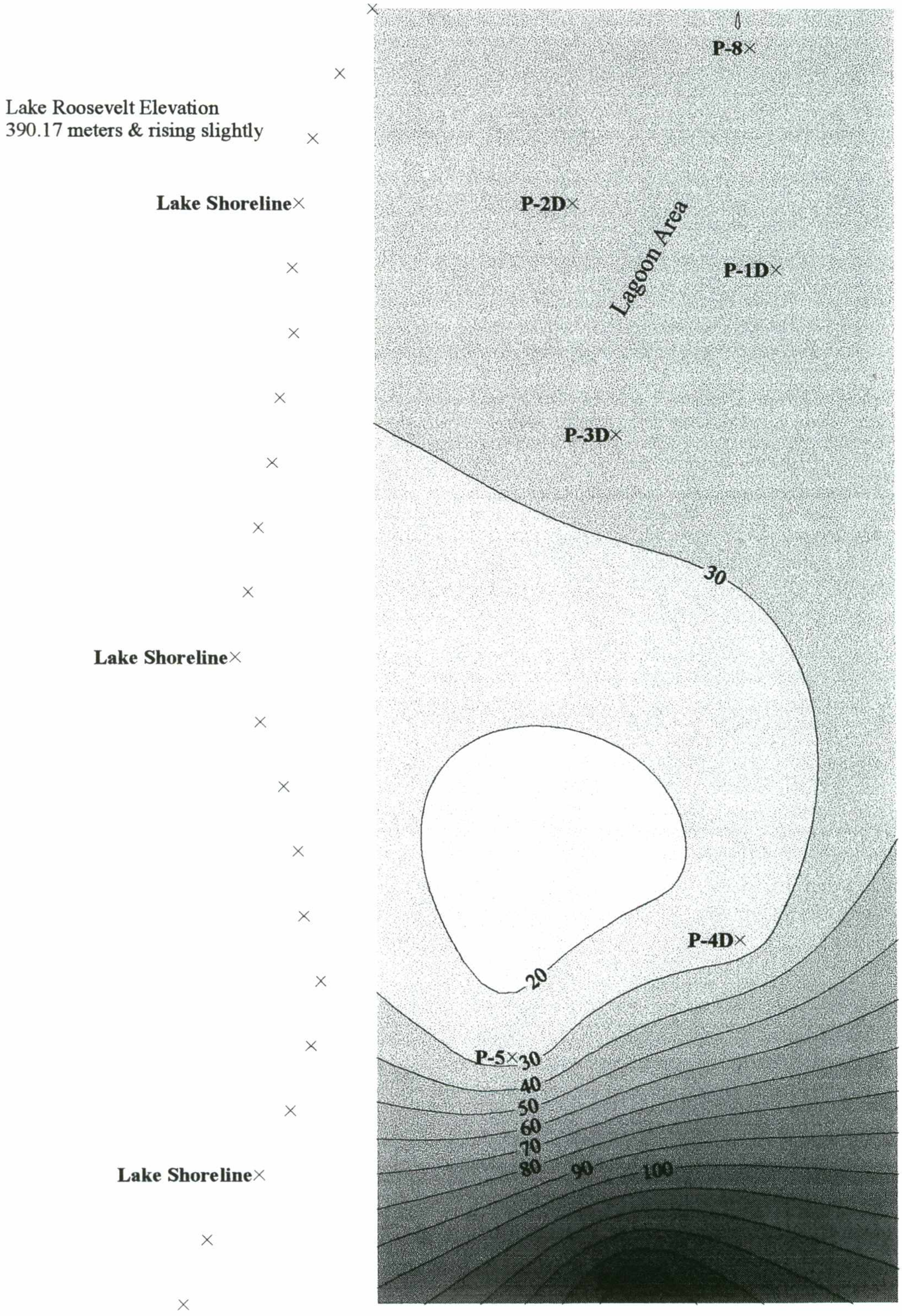


Dissolved Iron in Groundwater (ug/L) - 6/8/95

Contour Interval = 10 meters

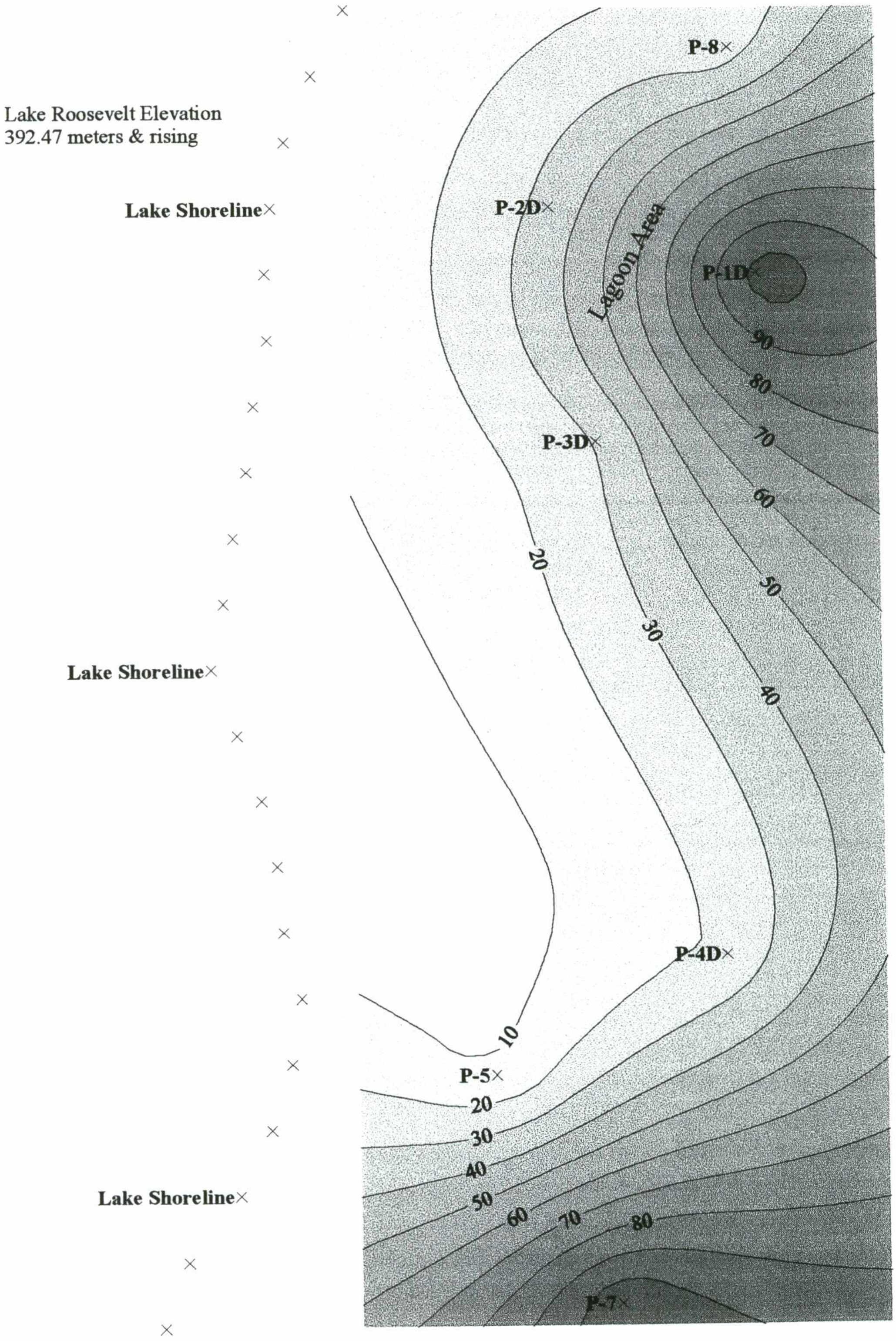
meters

0 50 100 150 200



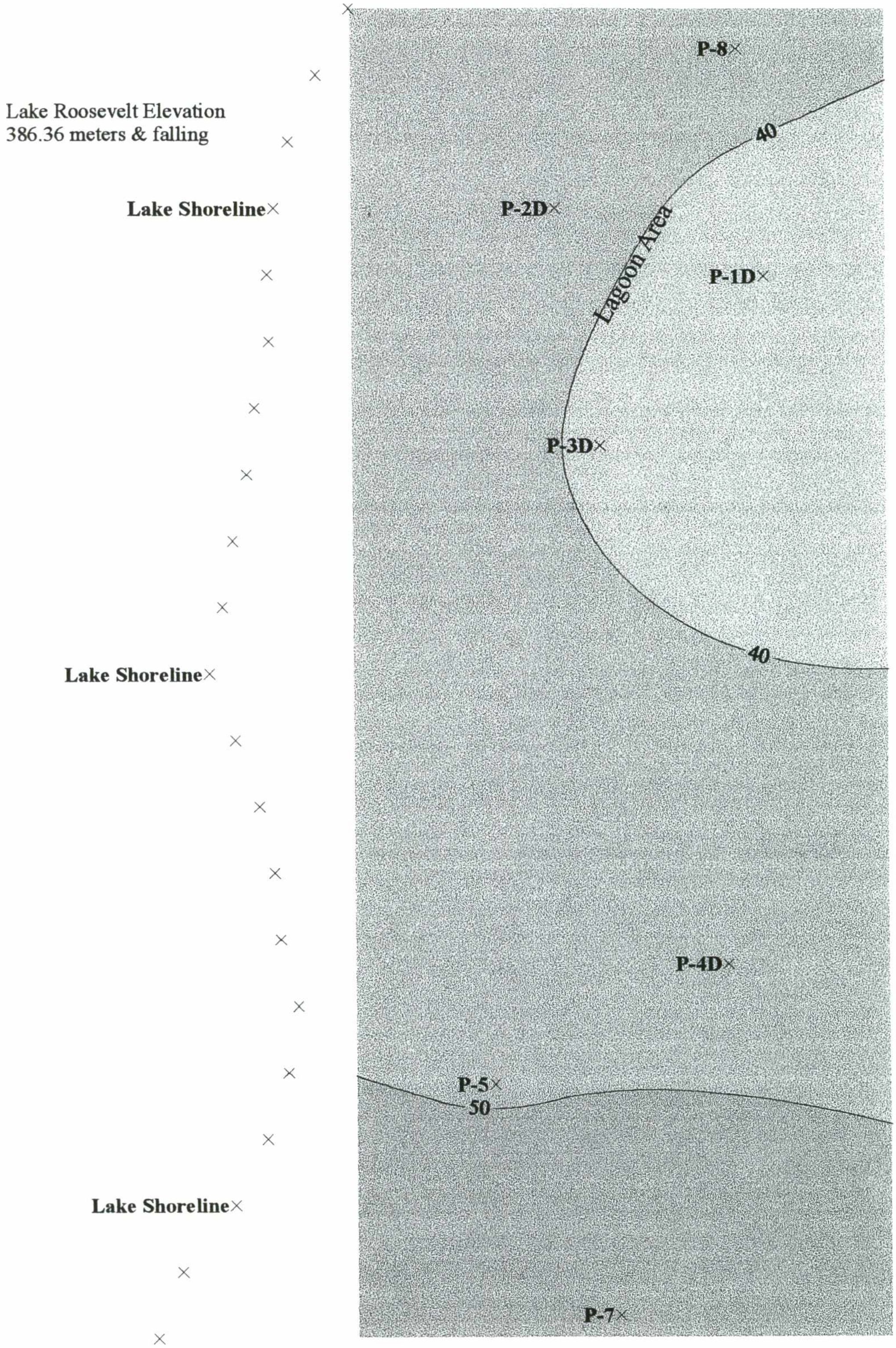
Dissolved Iron in Groundwater (ug/L) - 9/7/95

Contour Interval = 10 meters



Dissolved Iron in Groundwater (ug/L) - 12/5/95

Contour Interval = 10 meters

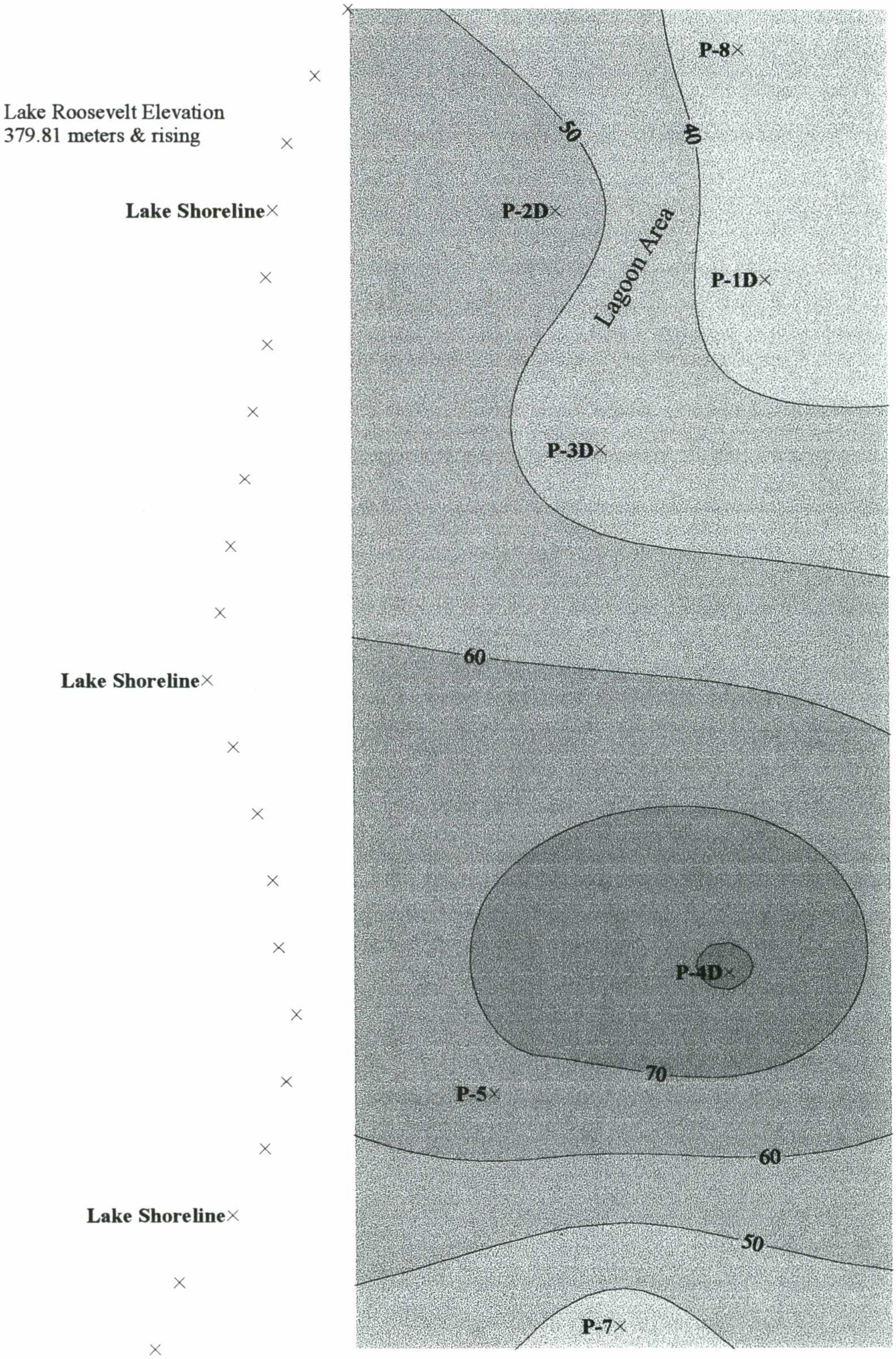


Dissolved Iron in Groundwater (ug/L) - 3/6/96

Contour Interval = 10 meters

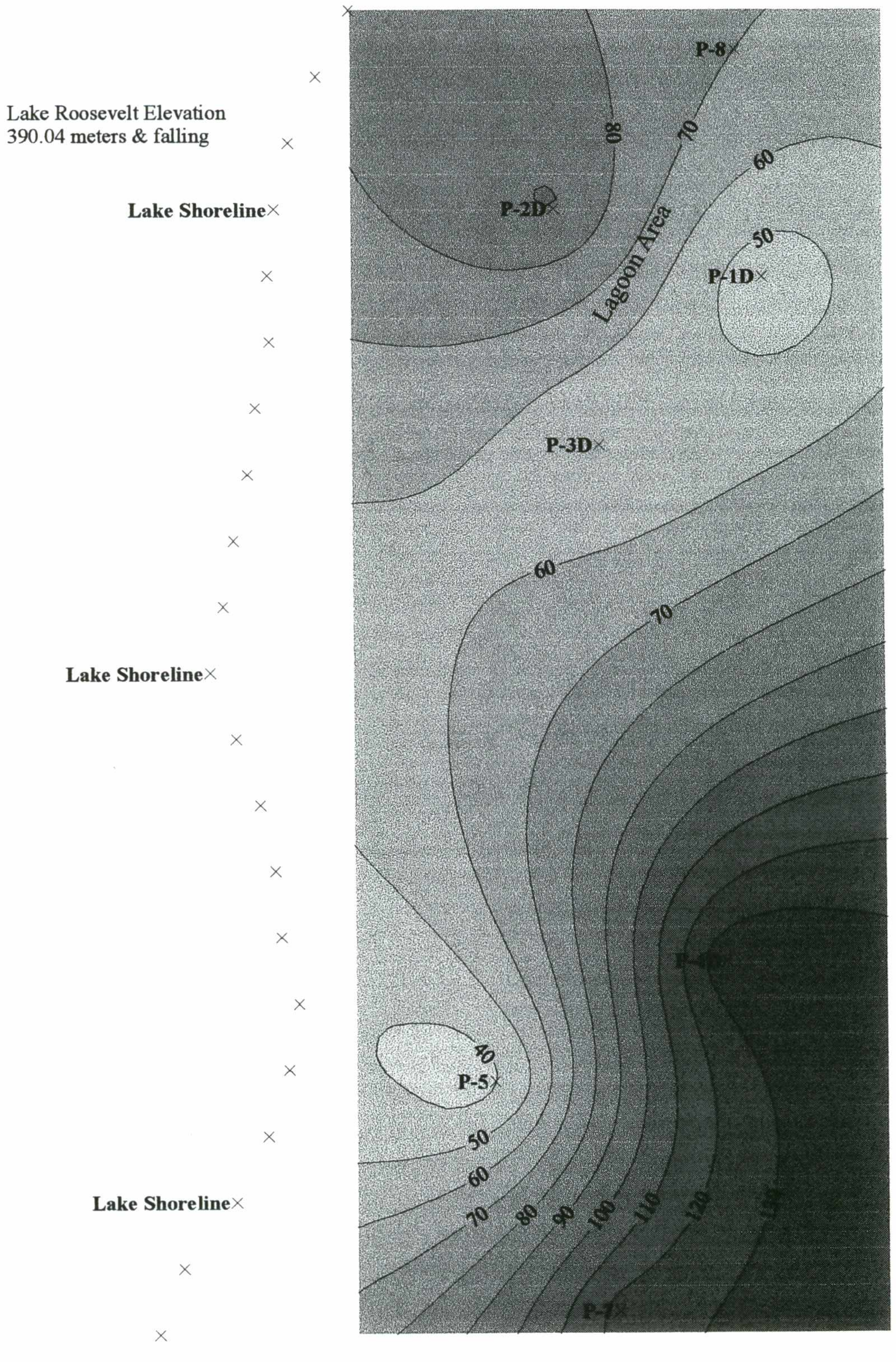
meters

0 50 100 150 200



Dissolved Iron in Groundwater (ug/L) - 6/7/96

Contour Interval = 10 meters

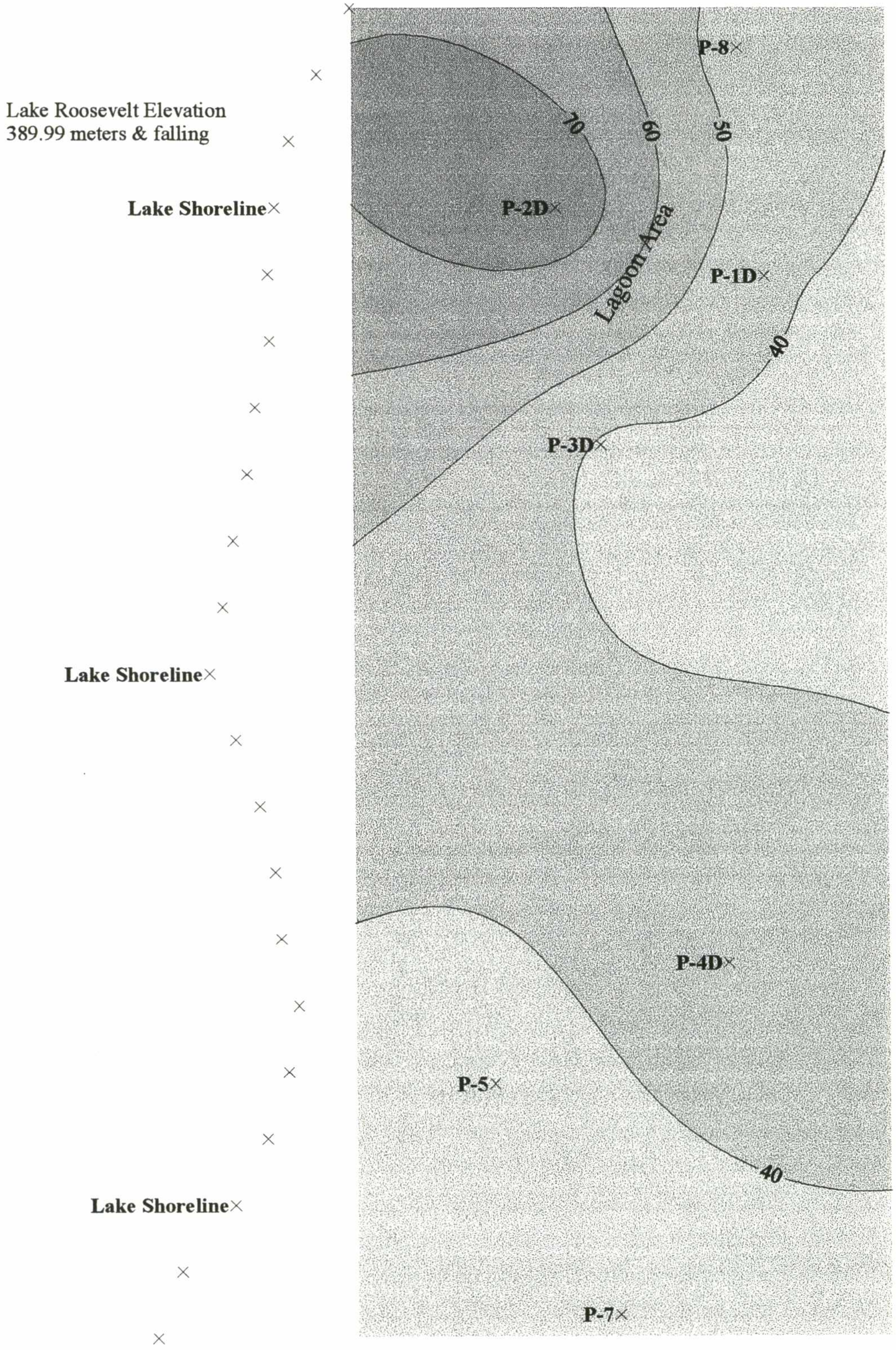


Dissolved Iron in Groundwater (ug/L) - 9/12/96

Contour Interval = 10 meters

meters

0 50 100 150 200



Dissolved Iron in Groundwater (ug/L) - 12/11/96

Contour Interval = 10 meters

meters

0 50 100 150 200