AN EVALUATION OF GROUND WATER NUTRIENT LOADING TO PRIEST LAKE, BONNER COUNTY, IDAHO

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Hydrology

in the College of Graduate Studies

University of Idaho

by

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May, 1995

1.0 INTRODUCTION

1.1 Statement of the Problem

The quality of Idaho lakes is of increasing concern, particularly when related to waste disposal and land use practices within the watersheds. Priest Lake, located in northern Idaho, is one of the highest quality water bodies in Idaho. However, there are concerns about preserving the existing quality of Priest Lake. The Priest Lake Project was funded by the 1992 Idaho State Legislature with the overall objective of preserving existing water quality while allowing the continuation of shoreline development.

One portion of the Priest Lake Project is determining nutrient loading via ground water from waste disposal practices near the shore line. This portion of the study is described as the "Groundwater/Wastewater Program Unit" of the Priest Lake Project. The stated objectives of the unit are:

> *Develop a program of groundwater sampling and/or estimation methods which would allow: 1) a lake nutrient value from groundwater, and 2) determine if generated septic effluent is percolating to potable wells, aquifers, and lake bays at unacceptable nutrient and bacteria concentrations.* (IDHW-DEQ, 1993, p.2)

Two areas of Priest Lake were selected in the Groundwater/Wastewater Program Unit as representative of the types of waste disposal practices that may impact the lake. The two study areas selected are: 1) the Kalispell Bay area, chosen as point source location for possible nutrient loading and 2) the Granite Creek area, chosen a non-point source location for possible nutrient loading (see Figure 1). The Kalispell Bay area has two sewage lagoon systems that are potential sources of nutrients for the lake. The septic sources for nutrients in the Granite Creek area are on-site residential subsurface disposal systems. The Kalispell Bay area and Granite Creek area are typical of point and non-point nutrient loading sources in the Priest Lake area.

This report describes the study performed on the Kalispell Bay and Granite Creek areas of Priest Lake and presents the conclusions and recommendations drawn from that study.

1.2 Purpose and Objectives

The purpose of this project is to provide ground water related nutrient flux information as part of the overall nutrient balance study on Priest Lake. The general objective of this study is to describe the hydrogeologic and ground water quality characteristics of the Kalispell Bay area and Granite Creek area and estimate the nutrient loading into Priest Lake via ground water in these areas.

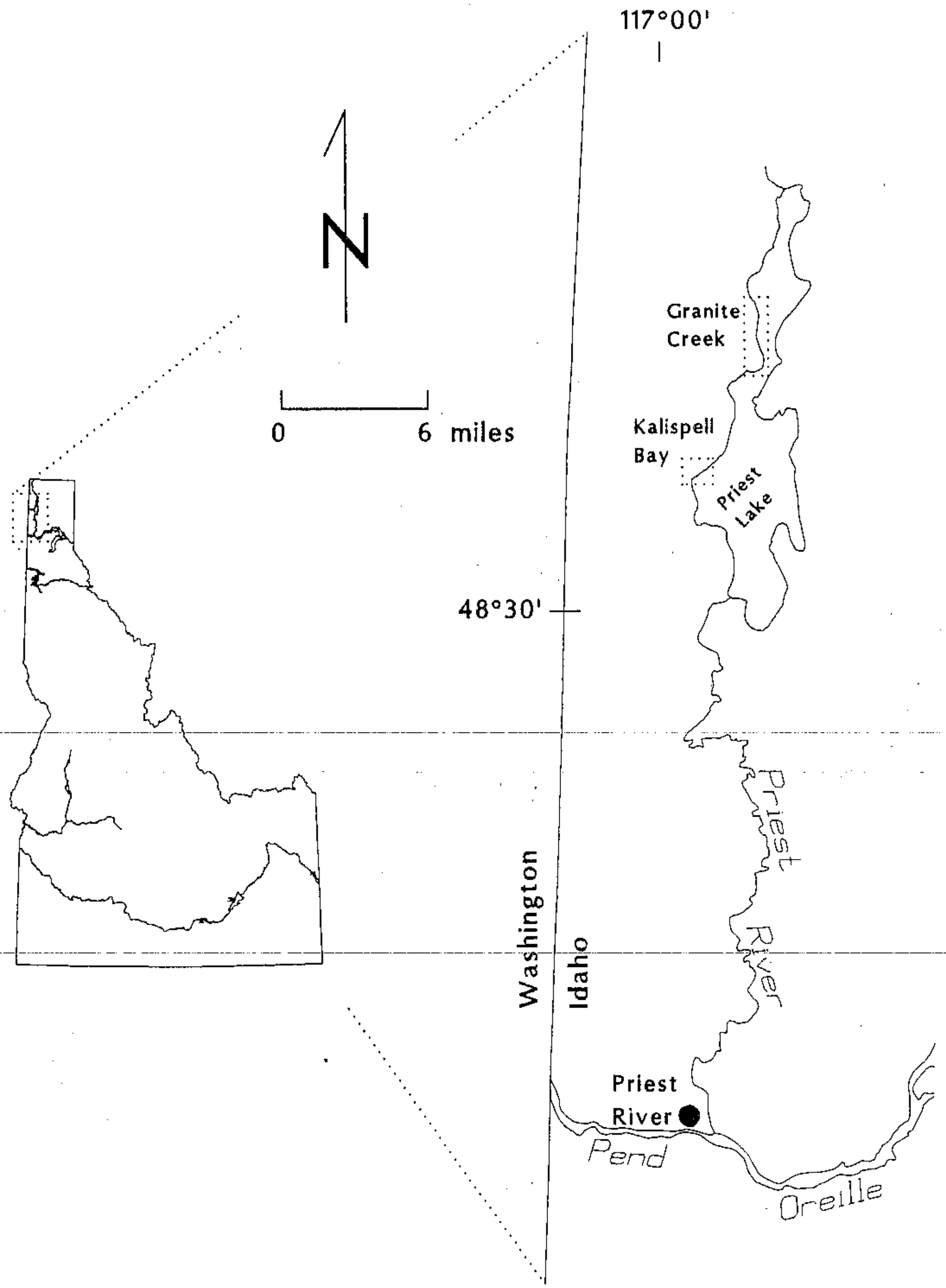

Figure 1. General location map of the Priest Lake area.

1.2.1 Specific Objectives

The specific objectives of this study are to:

1. Describe the hydrogeology of the study areas.
2. Describe ground water flow systems in the study areas.
3. Describe the ground water quality of the study areas.
4. Estimate the nutrient loading into Priest Lake from the study areas.
5. Present conclusions and recommendations.

1.3 Method of Study

The method of study used for this project was as follows. The first step was the collection and examination of available geologic and hydrogeologic information for the Priest Lake area, particularly the Kalispell Bay and Granite Creek study areas. Well locations and stratigraphic information was compiled. A field inventory of existing well sites was performed; the collected data were integrated with the previously compiled database. Geophysical investigations using surface resistivity techniques were made in both study areas to provide information regarding depth to bedrock. Additional wells were constructed in both study areas using hollow-stem auger and hand-driven techniques. Water level and water quality data were collected from the constructed wells and selected existing wells at regular intervals. The water quality samples taken from the wells were analyzed for various

2.0 HYDROGEOLOGIC SETTING

2.1 Priest Lake topography and geologic setting

Priest Lake is located in the northern portion of Bonner county, Idaho, near the Idaho-Washington border (see Figure 1). The lake is situated along the western flank of the Selkirk mountain range in a twenty mile long, north-south trending valley known as the Priest Lake Basin (Savage, 1967). Formed through the action of Pleistocene-epoch glaciation, Priest Lake is 18.5 miles long, approximately 0.5 miles wide with an overall area of 10 square miles and a maximum depth of 325 feet near the eastern shore of the lake. A dam at Outlet Bay, Idaho controls the surface (pool) elevation of the lake, keeping an average summer pool elevation of 2438 feet above mean sea level (MSL). The lake is lowered in the winter months to an average pool elevation of 2434 feet MSL (USGS, 1993). In 1992 the lake contained a maximum 127,800 acre·ft of water during the summer months and a minimum 46,900 acre·ft of water during the winter (USGS, 1993).

The country rock of the Priest Lake area is composed of two major types: (1) the granodiorties and related rocks of the Cretaceous-period Kaniksu batholith and (2) the argellites, siltites, quartzites, and other associated rocks of the Precambrian-age Belt Supergroup (see Figure 3). In many portions of the region surrounding Priest Lake, these country rocks form the basement for deposits of Quaternary

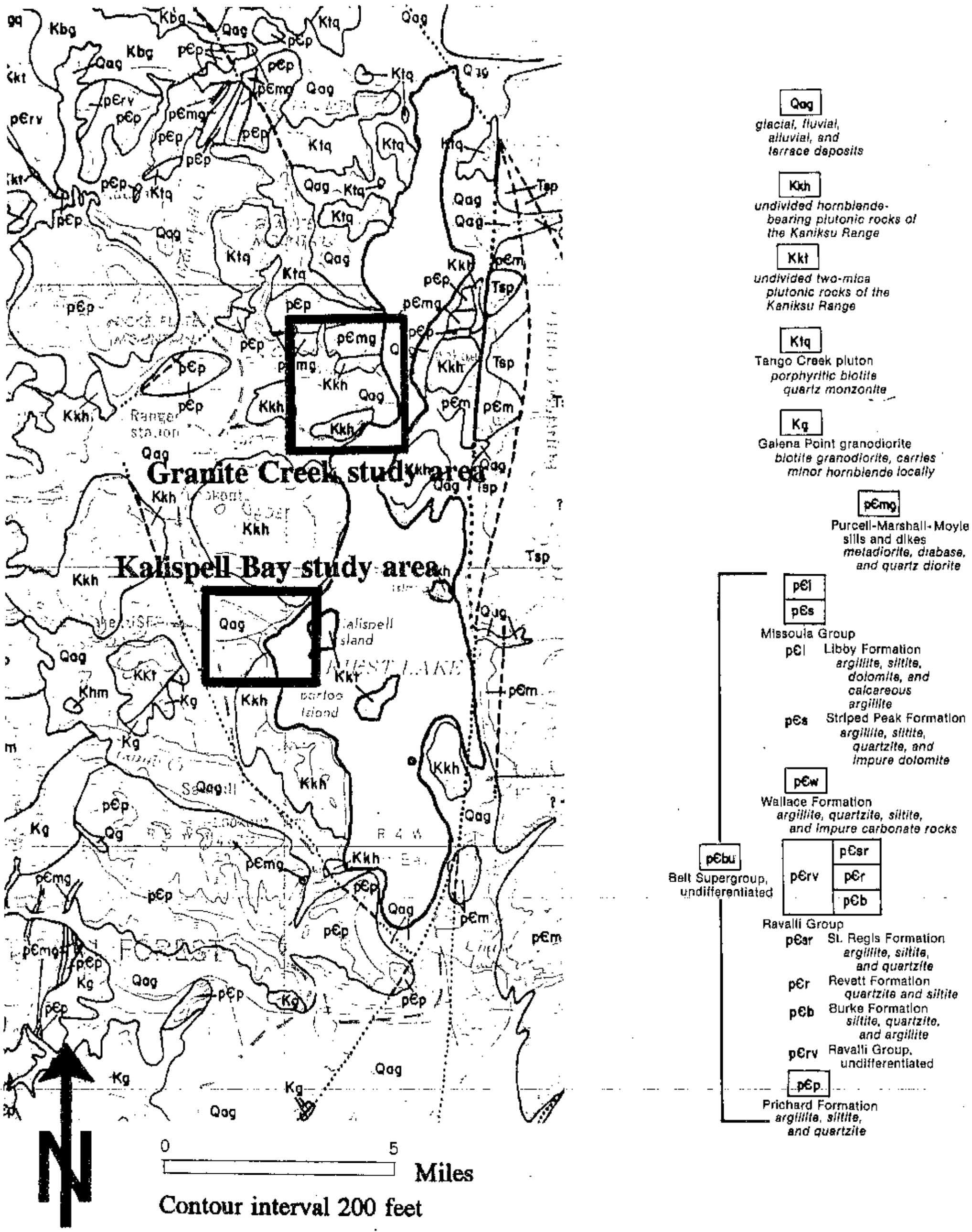

Figure 3. General geological map of the Priest Lake area (after Aadlan and Bennett, 1979).

period unconsolidated sediments. The Pleistocene glaciation created large accumulations of glacial debris derived from the surrounding country rock, while more recent sediments are alluvial and fluvial deposits associated with streams and stream outwash.

2.2 Hydrogeology of the Kalispell Bay study area

2.2.1 General setting of the Kalispell Bay study area

The Kalispell Bay study area is located in Section 12, Township T.60N, R.5W of Bonner County, Idaho, along the south-western shore of Priest Lake (see Figure 4). The study area boundaries are defined as the section lines of Section 12 to the north and west and the Priest Lake shoreline to the east and south (see Figure 4). This boundary was selected based on the geology, topography, and demographics of the Kalispell Bay area combined with the purpose of the study.

The study area is moderately developed, with one large subdivision in the center of the section and numerous homes along the bay shore. Many of the residences in the area are occupied year-round. The sewer collection system and lagoon are utilized by all area residents for septic disposal. Water for residential use is supplied by wells in the area; the subdivision is supplied by a single well, while homes near the lake use individual private wells.

The topography of the study area (see Figure 4) is composed of a gently sloping shoreline, which steepens rapidly with increasing distance from the lake, except for a local

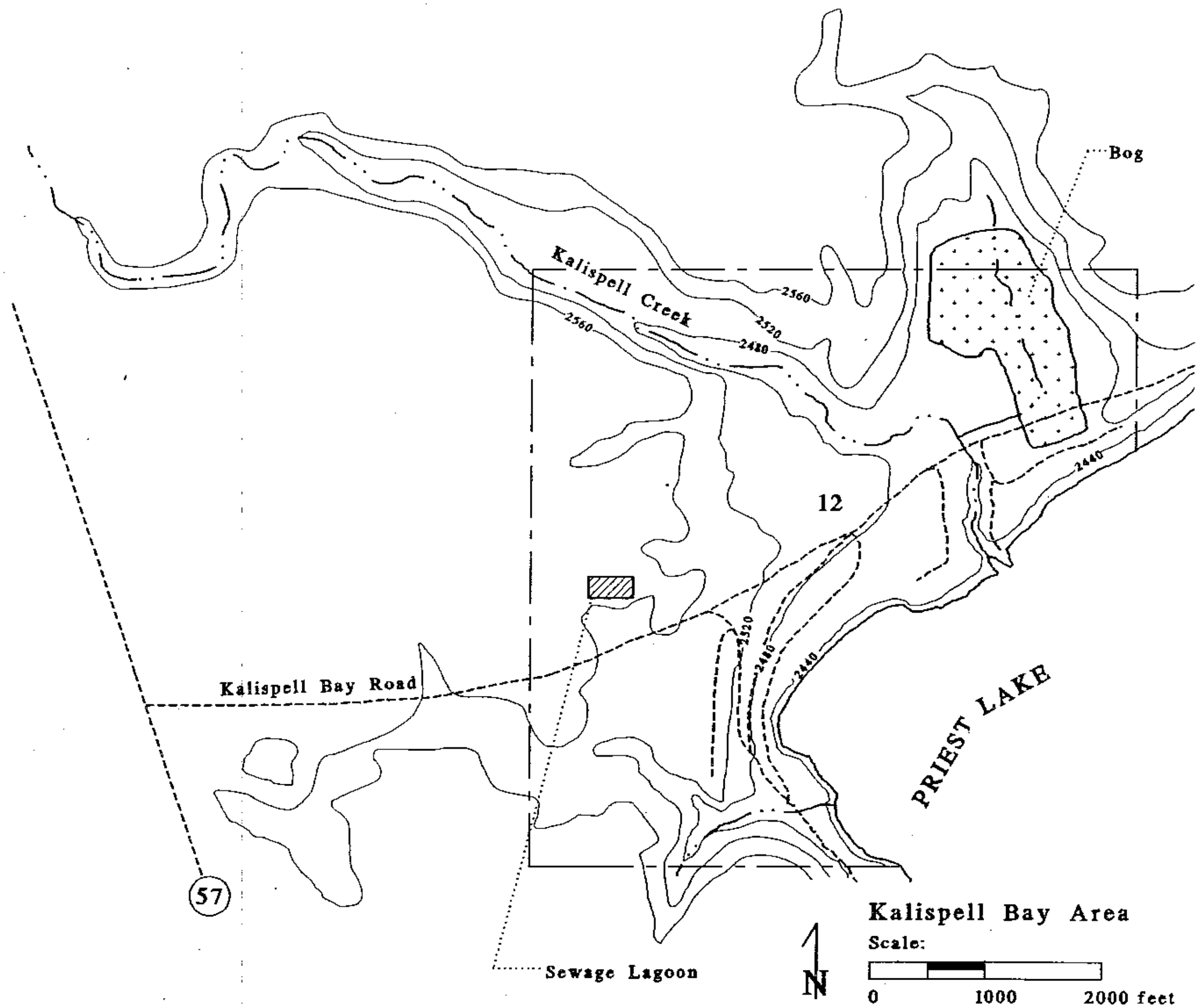

Figure 4. General location map and topography of the Kalispell Bay study area.

flat area extending along Kalispell Creek. The flat area is wide at the mouth of Kalispell Creek and decreases in width with distance inland. Geologically, the basement rock is composed of granodiorite, which outcrops in the southwestern and northeastern portions of the study area. The overlying sediments are primarily glacial deposits with minor alluvial and fluvial deposits associated with Kalispell Creek.

2.2.2 Review of available geologic information for the Kalispell Bay study area

The available well driller's reports for wells located in the Kalispell Bay study area were collected from the State of Idaho Department of Water Resources in order to describe the subsurface stratigraphy. Seventeen well logs were gathered for section 12 and the corresponding wells were approximately located through use of Bonner County land ownership records. Additionally, six wells without well logs were located and incorporated into the study, creating a set of 23 existing wells available for data collection (see Table 1).

All wells in the study area to have reported discharge rates of three to 50 gallons per minute (gpm). As indicated by the logs, the wells in the area have depths below surface ranging from 37 to 130 feet. There was no report of encountering bedrock in any of the wells. Many of the deeper wells (greater than 37 feet) were reported to be flowing at land surface or have static water levels very near the surface.

Table 1. Existing wells in the Kalispell Bay study area.

Property Owner	USPLS Legal Location (¼, ¼, ¼, S, T, R)	Location Description	Well Number	Well Log
Anderson, R.	NW,NW,SE,12,60N,5W	Lot 10E, Schneid Bch #1, 2	12dbb3	Yes
Bemis, R.	NE,NE,SW,12,60N,5W	Chas. Schrimp Tract	12caa7	Yes
Carper, R.	SE,SW,NE,12,60N,5W	Lot 1, Schneid Bch #2, 2	12acd7	Yes
Catlow, C.	NW,NW,SE,12,60N,5W		12dbb3	No
Depoala,M.	NW,NW,SE,12,60N,5W	Lot 9E, Schneid Bch #1, 2	12dbb4	Yes
Dobson, C.	NW,SE,NE,12,60N,5W	Schneid Bch #2, 2	12adb2	Yes
Foster, C.	SE,SW,NE,12,60N,5W	Lot 6, Schneid Bch #2, 1	12acd2	No
Joyce, F.	NE,NE,SW,12,60N,5W	Lot 2, Schneid Bch #1, 1	12caa1	Yes
Landa, J.	NE,NE,SW,12,60N,5W	S½ Lot 27, Schneid Bch #1	12caa8	Yes
Lea, J.	SE,NE,SW,12,60N,5W	Lot 10, Schneid Bch #1, 1	12cad1	No
Marzetta, A.	SE,SW,NE,12,60N,5W	Lot 2, Schneid Bch #2	12acd1	Yes
Odell, H.	NW,NW,SE,12,60N,5W	Lot 8E, Schneid Bch #1, 2	12dbb1	No
Parker, D.	SE,SW,NE,12,60N,5W	Lot 7, Schneid Bch #2,1	12abd4	Yes
Poster, B.	NE,SE,SW,12,60N,5W	Priest Lake Marina	12cda1	Yes
Rudie, G.	SE,NW,NE,12,60N,5W	E. of Kalispell Ck.	12abd3	Yes
Rudie, G.	NE,NE,SW,12,60N,5W	Lot 27, Schneid Bch #1, 2	12caa3	Yes
Rudie, G.	NE,NE,SW,12,60N,5W	Lot 3E, Schneid Bch #1, 2	12caa5	Yes
Rudie, G.	NE,NE,SW,12,60N,5W	Lot 5E, Schneid Bch #1, 2	12caa6	Yes
Schneider Subdiv.	NW,SE,NW,12,60N,5W	Lot 7, Blk. 4, Schneid. Sub.	12bdb	Yes
Stern, C.	SE,NE,NE,12,60N,5W		12aad	Yes
Thompson, J.	SE,NE,SW,12,60N,5W	Lot 4, Schneid Bch #1, 1	12cad4	No
U.S. Forest Service	NE,SE,SW,12,60N,5W	Above P.L. Marina	12cda4	Yes
Weitz, C.	SE,SW,NE,12,60N,5W	Lot 9, Schneid Bch #2, 1	12acd6	No

Stratigraphically, the well logs reported "sands" or mixed "sands and gravels" as the dominant sediment type in the area. In some scattered well logs there were reports of "clay" layers at depth. However, other wells within the same area reported no evidence of "clay" layers; this suggests that the clay layers are laterally discontinuous within the area. The examination of the well logs yielded no information regarding the overall thickness of the sediments in the study area. The thickness of sediments is a critical input for estimating nutrient loading rates from ground water.

2.2.3 Geophysical investigations in the Kalispell Bay study area

A geophysical investigation utilizing surface resistivity was performed by the University of Idaho to determine depth to bedrock and the presence of any lateral stratigraphic variations. A detailed description of the investigation is presented in Appendix A. An expanding Schlumberger array study was performed at two sites in the area (see Figure 5). These sites were selected in order to provide easy placement of the resistivity lines, as most of the area is heavily vegetated.

The results of the resistivity survey at Site 1 indicate a depth to bedrock of approximately 245 feet below land surface. Surface elevation in the area is approximately 2570 feet MSL, yielding an approximate bedrock elevation of 2325 feet MSL at this location. The results at Site 2 indicate a depth to bedrock of approximately 255 feet below land surface. Surface elevation at this site is approximately 2460 feet MSL, yielding an approximate bedrock elevation of 2205 feet MSL. The distance between the two sites is approximately 4000 feet, indicating a bedrock slope of three percent towards the lake.

2.2.4 Field drilling activity in the Kalispell Bay study area

Shallow wells were installed to expand the hydrogeologic, geologic, and water chemistry knowledge of the shallow portion of the sediments in the study area. Twelve wells were installed within the Kalispell Bay study area, seven using a hollow stem auger and five by hand driving. Tables 2 and 3 describe methods of installation and the types of well material were used in construction of these wells. A general well construction diagram is presented in Figure 6. The depths of the wells ranged between seven and 14 feet below land surface. The wells were located to create an even distribution along the shore of Kalispell Bay in order to spatially quantify the quality of ground water entering into the lake.

During drilling, the downhole cuttings returned from both the hollow-stem auger (HSA) technique and the hand auguring of pilot holes for the driven wells were field inspected. The shallow sediments are very similar from site to site, and usually composed of a coarse grained sand with minor fine grains and an occasional pebble or cobble size clast. Approaching Kalispell Creek, the collected drill cuttings occasionally indicate the presence of minor clay lenses, but

Table 2. Constructed wells in the Kalispell Bay study area.

Property Owner	USPLS Legal Location (¼, ¼, ¼, S, T, R)	Method of Construction	Screen Length (feet)	Filter Pack Thickness/Length (inches/feet)	Surface Seal Depth (feet)	Well Number
Poster	NE,SE,SW,12,60N,5W	Driven	2	1/7	4	12cda2
Rudie	NE,SE,SW,12,60N,5W	HSA*	2	3/4.5	7	12cda3
Lea	SE,NE,SW,12,60N,5W	HSA	2	3/5	9	12cad2
Thompson	SE,NE,SW,12,60N,5W	Driven	2	1/5	7	12cad3
Thompson	SE,NE,SW,12,60N,5W	Driven	2	1/7	5	12cad5
Rudie	NE,NE,SW,12,60N,5W	HSA	2	3/5	7	12caa2
Rudie	NE,NE,SW,12,60N,5W	Driven	2	1/5	6	12caa4
Odell	NW,NW,SE,12,60N,5W	HSA	2	3/5.5	7	12dbb2
Foster	SE,SW,NE,12,60N,5W	Driven	2	1/7	5	12acd3
Warren	SE,SW,NE,12,60N,5W	HSA	2	3/4.5	8	12acd4
Weitz	SE,SW,NE,12,60N,5W	HSA	2	3/4.5	9	12acd5
Ridenour	NW,SE,NE,12,60N,5W	HSA	2	3/4.5	9	12adb1

* HSA = Hollow-Stem Auger

Table 3. Summary of methods and materials for constructed wells in the Kalispell Bay study area.

Method of Construction	Well Material	Well Screen Size	Filter Pack	Surface Seal
Hollow-Stem Auger (HSA)	2" PVC Plastic	10-slot 0.010"	10-20 Sand	Bentonite + Grout
Hand-Driven	2" Stain-less Steel	10-slot 0.010"	Natural	Bentonite

these are very thin and of limited lateral extent. Samples for laboratory analysis were retrieved during the construction of pilot holes for two of the driven wells, 12caa4 and 12acd5. A grain size analysis (see Appendix B) characterized these samples as well sorted, sub-angular to rounded, coarse-to-very fine sands with ten percent sub-rounded very fine gravels.

All constructed wells encountered saturated sediments within the first 10 feet of drilling. All wells in the study area produce water at minimum rate of two gallons per minute. Most of the static water levels measured in the wells were within five feet of land surface.

2.2.5 Conceptual hydrogeologic model of the Kalispell Bay study area

A conceptual hydrogeologic model for the Kalispell Bay area was constructed based on the geologic and hydrogeologic data. A thick, unconsolidated sand aquifer is present overlying low hydraulic conductivity granitic bedrock. Neither the well logs nor the geophysical investigations indicated the presence of a laterally continuous confining layer (clay) in study area. A single, unconfined aquifer occurs in the area.

A geologic cross-section for the Kalispell Bay study area was developed (see Figure 7) along a line of section KR-KR', using the known geology for the area and the depth to bedrockbelow land surface determined by the geophysical survey. The location of the cross-section is shown on Figure 5. The section describes a bedrock topography dipping steeply from west to east under the western portion of the study area. Under Kalispell Bay, the dip of the bedrock surface changes and rises sharply to the east, outcropping on Kalispell Island. The sharp rise in the bedrock surface under Kalispell Bay truncates the aquifer under the lake, creating a boundary to eastward ground water flow near Kalispell Island.

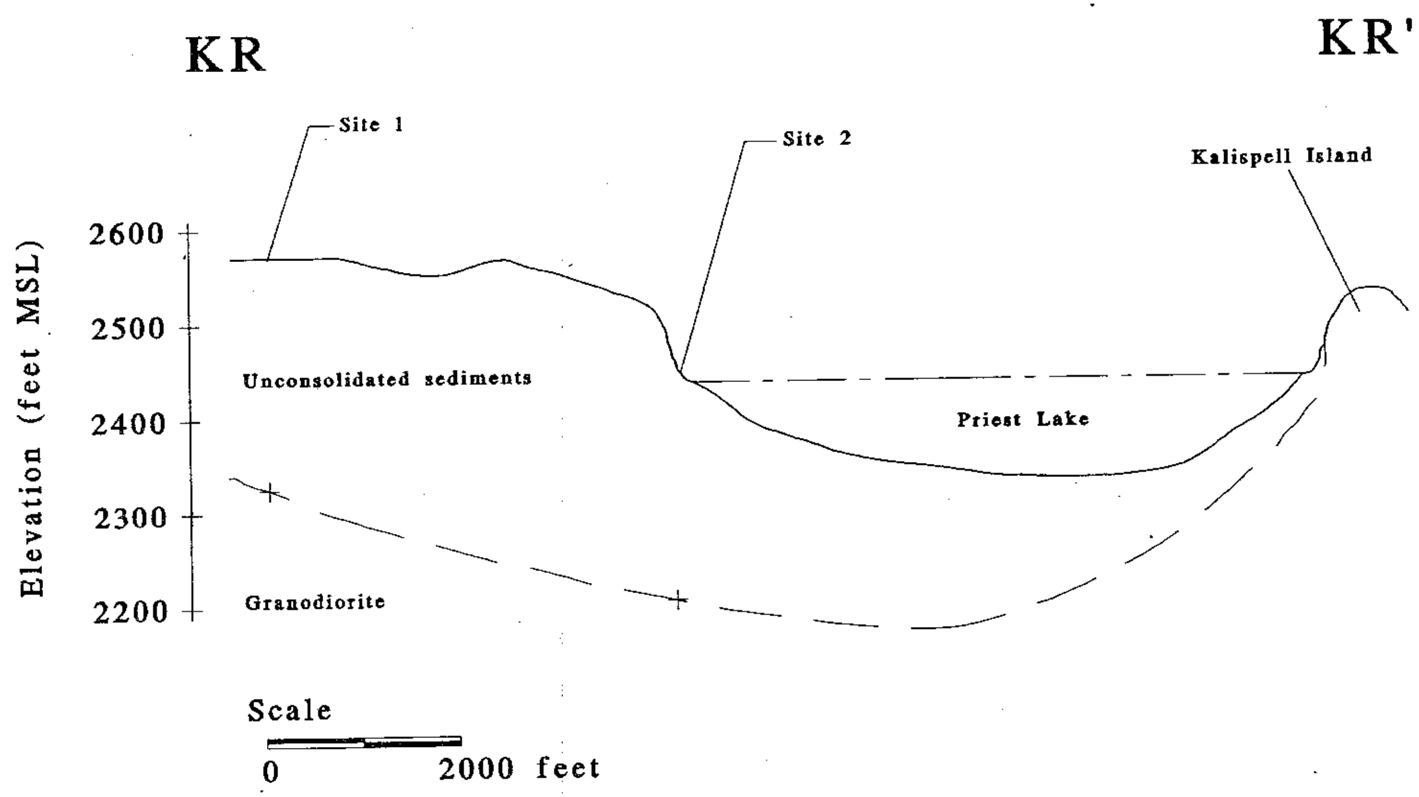

Figure 7. Inferred geologic cross-section along line KR-KR', Kalispell Bay study area.

3.2 Ground water flow systems in the Kalispell Bay study area

3.2.1 Introduction

A set of 28 wells (see Table 7) is used to describe the ground water elevation in the Kalispell Bay study area. The observation set is spatially distributed along the shore of Priest Lake and consists of existing wells plus wells constructed for this study (see Figure 13). Water levels were recorded from the observation wells at varied intervals over a five-month period (see Table 8).

The wells were divided into two groups, shallow and deep, for examining the horizontal and vertical ground water gradients present in the Kalispell Bay study area. An arbitrary well depth of 20 feet was chosen to distinguish "shallow" wells (well depth less than 20 feet) from "deep" wells (well depth greater than 20 feet). Using this division, the wells were divided into two sets with the constructed wells plus a single existing well, 12cad1, forming the shallow well set and the remaining existing wells forming the deep well set.

3.2.2 Description of ground water flow patterns in the Kalispell Bay study area

Water level elevations recorded on October 22, 1993 are compared with the observation well depth below land surface (see Figure 14) in order to identify any vertical gradient within the study area. Well depth below land surface is believed to be the best representation of the open interval

Table 7. Observation wells for the Kalispell Bay study area.

Well Number	Well Depth (feet bgs)	Screened Interval (feet bgs)	Easting	Northing	Elevation (feet MSL)	
					Well Head	Well Bottom
12cda1	63	58-63	2263	540	2450.9	2387.9
12cda4	100	77-82	1955	847	2487.6	2387.6
12cda2	11.5	9.5-11.5	2389	593	2445.8	2434.3
12cda3	11.5	8.5-11	2143	795	2444.8	2433.3
12cad1	6	open	2164	1120	2446.3	2440.3
12cad2	13.0	10-12.5	2176	1172	2448.7	2435.7
12cad4	63	N/A	2356	1471	2449.9	2386.9
12cad3	12.0	10-12	2381	1427	2445.1	2433.1
12cad5	12.0	10-12	2406	1541	2446.4	2434.4
12caa1	55	open	2408	1673	2452.5	2395.0
12caa2	11.7	8.8-11.3	2671	1805	2450.9	2439.2
12caa3	91	86-91	2715	1840	2450.3	2359.3
12caa5	100	91-96	2630	1937	2471.4	2371.4
12caa4	11.0	9-11	2833	1902	2443.3	2432.3
12caa6	85	79-84	2862	1972	2447.1	2362.1
12dbb1	99	N/A	3005	2007	2448.0	2349.0
12dbb2	11.0	8-10.5	3012	2060	2447.0	2436.0
12dbb3	22	N/A	3372	2068	2443.9	2421.9
12acd1	63	58-63	3650	2134	2445.7	2382.7
12acd4	13.0	10-12.5	3687	2332	2443.9	2430.9
12acd3	12.0	10-12	3772	2306	2443.8	2431.8
12acd2	35	N/A	3854	2257	2445.1	2410.1
12acd6	64	N/A	3956	2574	2447.2	2383.2
12acd5	14.5	11.5-14	4024	2565	2446.4	2431.9
12acd7	79	74-79	4213	2881	2449.6	2370.6
12adb1	13.0	10-12.5	4536	3188	2451.2	2438.2
12adb2	130	70-130	4623	3215	2453.6	2323.6
12abd3	58	53-58	3637	4054	2463.8	2405.8

bgs = below ground surface
N/A = Not Available
open = no well screen; well is open at bottom

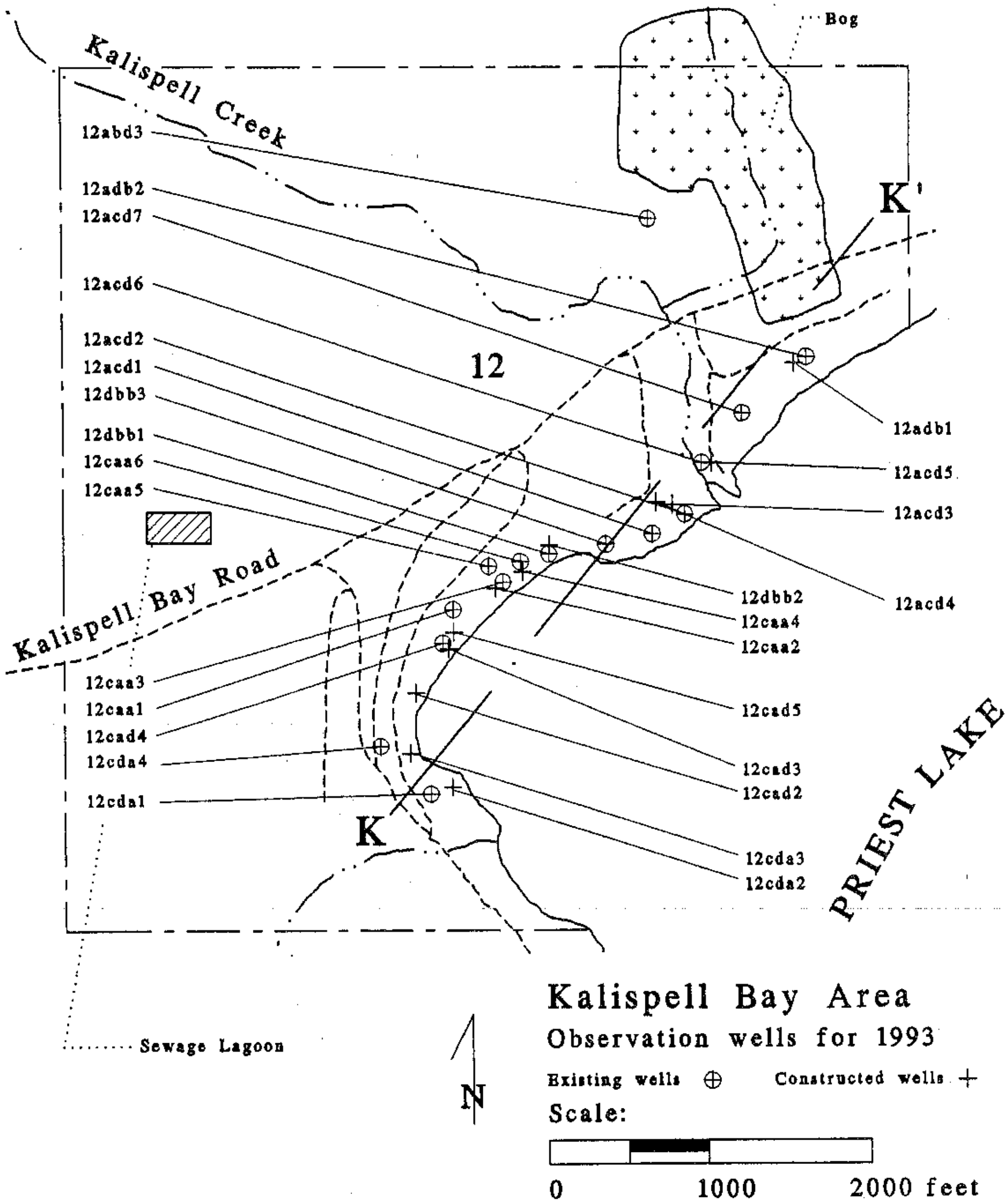

Figure 13. Location map of observation wells in the Kalispell Bay study area.

Table 8. 1993 observation well depth-to-water and water level elevations, Kalispell Bay study area.

Well Number	DEPTH TO WATER (1993)							WATER LEVEL ELEVATION (1993)						
	7/21	7/29	8/7	8/28	10/2	10/22	11/19	7/21	7/29	8/7	8/28	10/2	10/22	11/19
12cda1	1.80					2.16		2449.1					2448.7	
12cda4	33.00	33.05				33.16		2454.6	2454.5				2454.4	
12cda2			7.50	7.50	7.56	7.62	9.45			2438.3	2438.3	2438.3	2438.2	2436.4
12cda3			3.81	3.77	3.73	3.76	4.25			2441.0	2441.0	2441.1	2441.0	2440.5
12cad1				2.40							2443.9			
12cad2			1.16	1.15	1.10	1.26	1.35			2447.5	2447.5	2447.6	2447.4	2447.3
12cad4	flowing	flowing		flowing		flowing	flowing	2449.9	2449.9		2449.9		2449.9	2449.9
12cad3			5.57	5.71	5.77	5.75	7.40			2439.6	2439.4	2439.4	2439.4	2437.7
12cad5						6.30							2440.1	
12caa1				1.18							2451.3			
12caa2			1.11	1.10	1.11	1.16	1.36			2449.8	2449.8	2449.8	2449.8	2449.6
12caa3	flowing	flowing		flowing		flowing	flowing	2450.3	2450.3		2450.3	2450.3	2450.3	2450.3
12caa5	18.90	18.94				17.15	17.4	2454.5	2454.5				2454.3	2454.0
12caa4				4.50	4.56	4.62	6.10			2438.8	2438.8	2438.7	2437.2	
12caa6	flowing	flowing		flowing		flowing	flowing	2447.1	2447.1		2447.1	2447.1	2447.1	2447.1
12dbb1	flowing	flowing		flowing		flowing	flowing	2448.0	2448.0		2448.0		2448.0	
12dbb2			1.40	1.34	1.31	1.27	1.52			2445.6	2445.7	2445.7	2445.8	2445.5
12dbb3	2.30	2.40				2.43		2441.6	2441.5				2441.5	
12acd1		5.10		5.01		5.00	5.9		2440.6		2440.7		2440.7	2439.8
12acd4			3.25	3.15	3.18	3.15	4.00			2440.6	2440.7	2440.7	2440.7	2439.9
12acd3						3.15	4.00						2440.7	2439.8
12acd2		5.45		5.46				2439.7		2439.6				
12acd6	8.87	8.91		8.98		9.10	10.4	2438.4	2438.3		2438.2		2438.1	2436.8
12acd5			8.10	8.13	8.18	8.25	9.12			2438.3	2438.2	2438.2	2438.1	2437.2
12acd7	6.97	7.12				7.82	7.97	2442.7	2442.5				2441.8	2441.7
12adb1			4.25	4.63	4.65	4.61	4.62			2447.0	2446.6	2446.6	2446.6	2446.6
12adb2	0.00	0.00		0.00		0.00	0.00	2453.6	2453.6		2453.6		2453.6	2453.6
12abd3	10.34					11.50		2453.5					2452.3	

for the observation wells in the study area. The plot shows that all wells have water level elevations greater than the lake level elevation of 2438 feet MSL, indicating ground water flow to the lake throughout the study area. Some deeper wells have higher water level elevations than nearby shallow wells, indicating an upward vertical hydraulic gradient exists in portions of the study area. However, some of the deeper wells do not show this upward gradient.

Water level elevations of the deep (existing) wells in the Kalispell Bay study area (see Figure 15) appear controlled by three factors: 1) depth of the well, 2) proximity to Kalispell Creek, and 3) distance from the lake. Water level elevation in the wells increases with increasing well depth except in the vicinity of Kalispell Creek. This indicates that an upward vertical gradient exists in parts of the deeper portion of the aquifer. All deep (existing) wells have water levels higher than the mean pool elevation of Priest Lake and the water level elevations increase with increasing distance from the lake. This indicates ground water flows to Priest Lake from the deeper portion of the aquifer.

Deep (existing) wells in the vicinity of Kalispell Creek display water level elevations equivalent to those of nearby shallow/constructed wells. This indicates the absence of an upward vertical hydraulic gradient in the vicinity of Kalispell Creek. The water level elevations recorded from deep (existing) wells in this section are greater than the average surface elevation of Kalispell Creek, indicating

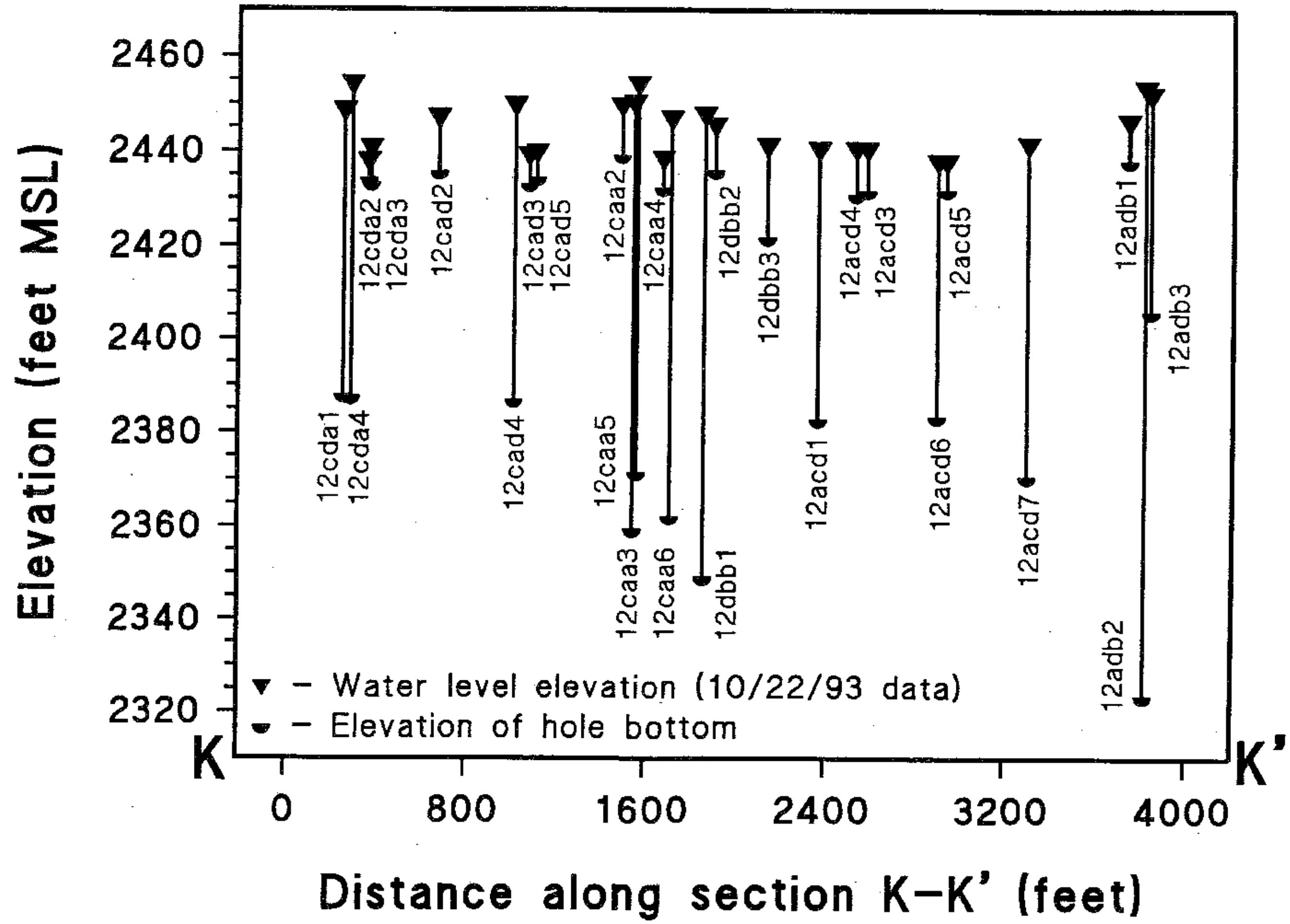

Figure 15. Water level elevation related to hole bottom depth along line K-K', Kalispell Bay study area.

ground water flow to Kalispell Creek in addition to flow to the lake.

The water level elevation in relation to well depth elevation along section line K-K' is plotted in order to examine the vertical and horizontal gradients (see Figure 15). From well 12cda1 to well 12dbb2 across the section presented in Figure 15 (southwestern portion), the deeper wells have higher water level elevations than the shallow wells, indicating an upward gradient in this portion of the study area. Wells 12dbb2 through 12adb1 show deep wells with water elevations about the same as the shallow wells, indicating that a vertical gradient is not present in this portion. From well 12adb1 through 12adb3 water level elevations in the deep wells are higher than the water level in the shallow well, indicating a return to an upward gradient. The portion without a vertical gradient is nearer to Kalispell Creek; wells displaying an upward hydraulic gradient are those farther from Kalispell Creek (see Figure 13). This is likely due to the hydrogeologic characteristics of the depositional environment associated with the Kalispell Creek delta. Examination of shallow (constructed) water level elevations (see Figure 16) shows that all shallow wells displayed water level elevations above the lake level, indicating a hydraulic gradient from the aquifer to the lake. Water level elevations recorded for wells 12cda2, 12cda3, 12cad3, 12caa4, 12acd4, and 12acd5 during August and October display water levels within two feet of lake water level elevation. Wells 12cad2, 12caa2,

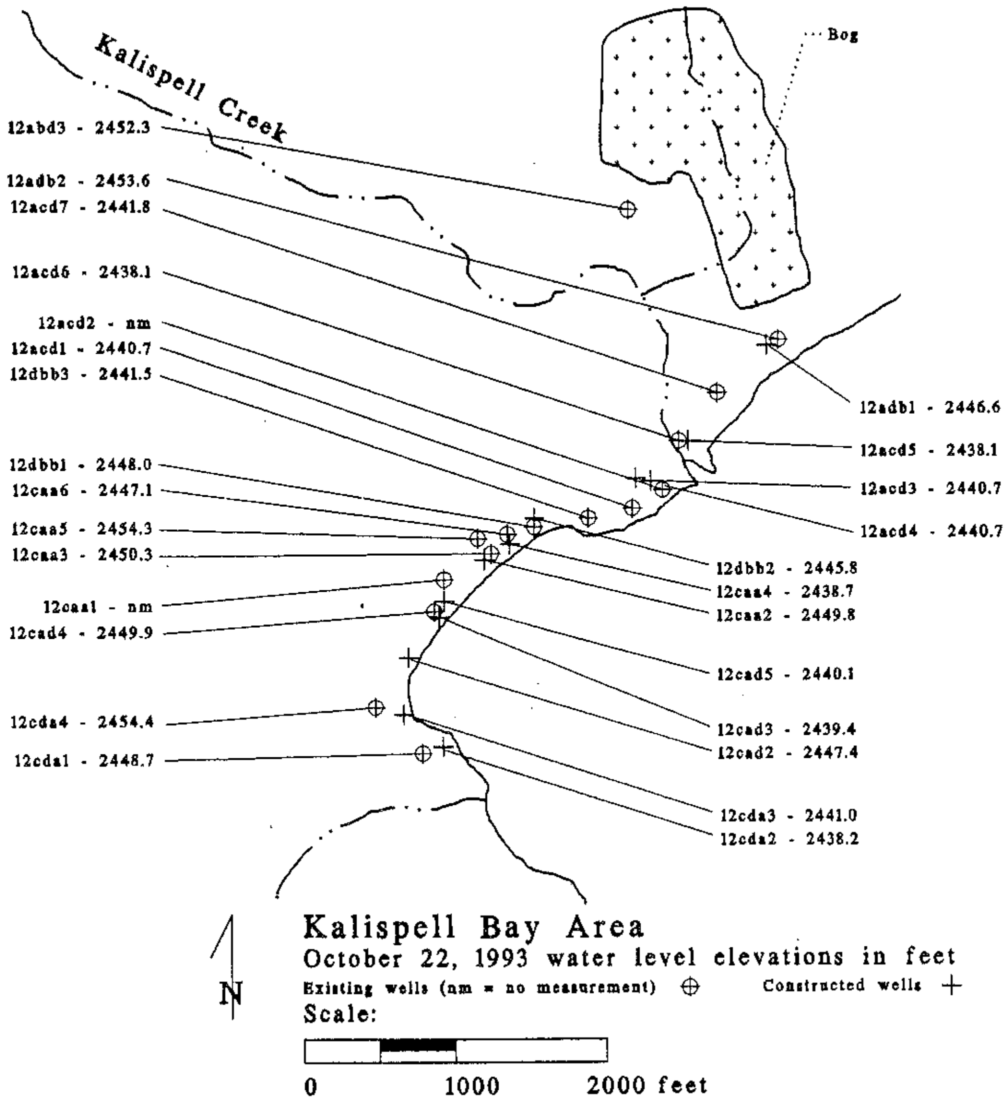

Figure 16. October 22, 1993 water level elevation data for wells in the Kalispell Bay study area.

12dbb2, and 12adb1 displayed water level elevations four or more feet above lake level. The difference in water level elevation between the two groups is likely due to a combination of the well's location in relation to Kalispell Creek and the well's proximity to a bog or apparent ground water seep.

The seasonal drawdown of Priest Lake occurrs each fall; the lake level was lowered from 2438 feet MSL in October, 1993 to 2435 feet MSL in November, 1993. The change in water level elevations from October to November recorded for the deep (existing) wells was analyzed to describe the ground water a response to lake drawdown (see Figure 17). Well 12acd6, located within 100 feet of Kalispell Creek, had the greatest water level decline of the measured wells, approximately 1.3 feet. Other wells proximal to Kalispell Creek reacted to lake lowering, but to a lesser degree.

Examination of the change in water level elevation from October to November for the shallow (constructed) wells (see Figure 17) reveals two distinct response patterns in the wells. Those wells with water level elevations four or more feet above October lake level displayed only slight response to lake level lowering. The wells with water level elevations only two or less feet above the October lake level displayed a significant response to lake lowering.

Plotting the water level elevation changes for both the deep and shallow wells along section K-K' (see Figure 18) shows the water level changes relating to lake lowering.

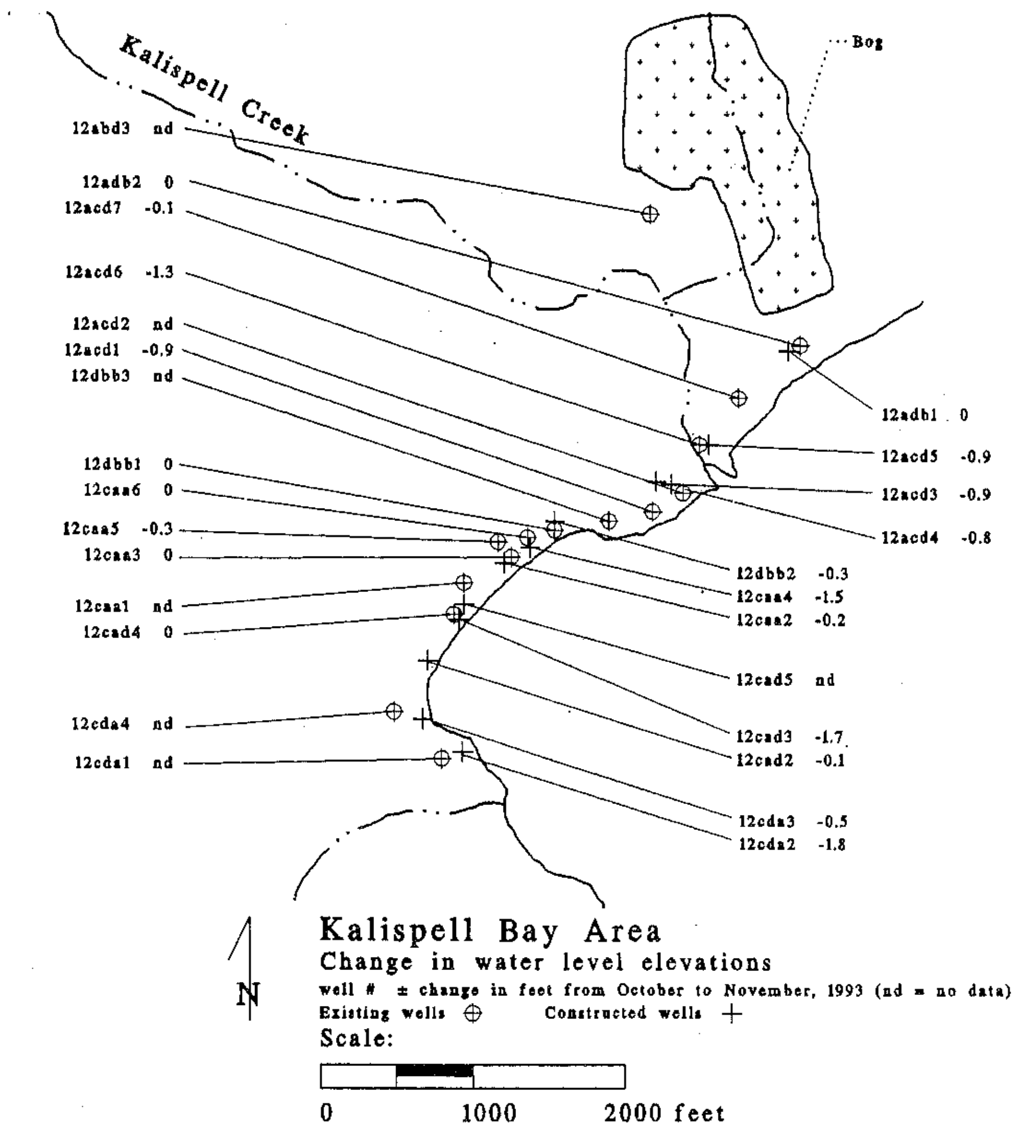

Figure 17. Change in water level elevations from October to November, 1993.

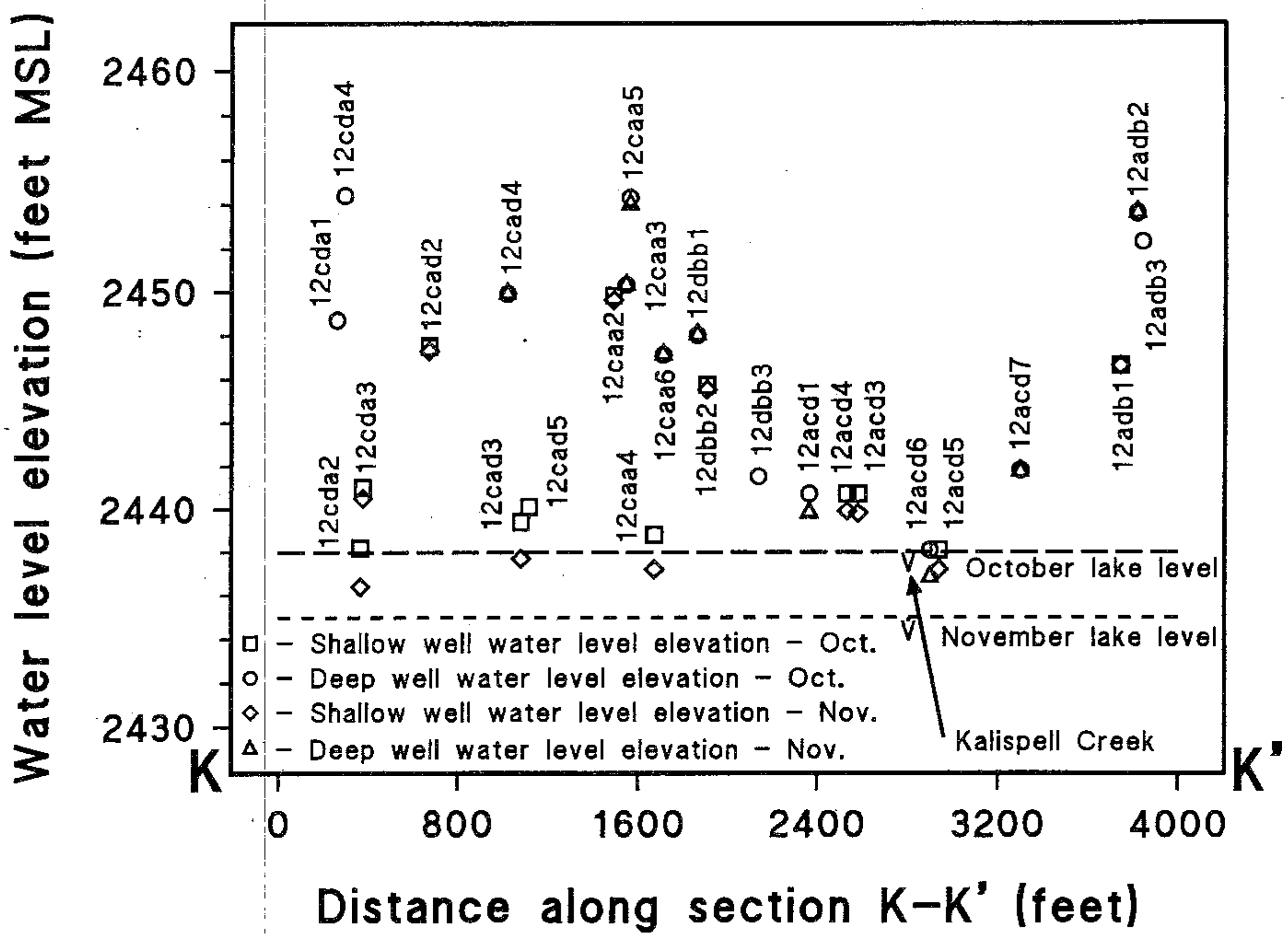

Figure 18. Water level elevation in relation to lake level elevation, October-November, 1993, Kalispell Bay study area.

Significant changes in ground water levels only occur in shallow wells where water level elevations are near lake level. Field observations indicate that the shallow (constructed) wells with water level elevations notably above lake level are located near bogs or apparent ground water seeps. This constant surface water source could account for the lack of water level elevation change. In the case of the wells not located near bogs or seeps, the water level elevation change is related more closely to the lake level change.

A composite of water level elevation data were created from the months of July, August, and October, when lake level was nearly constant. Water level elevation contour maps were then constructed for the shallow and deep portions of the aquifer. The shallow water level elevation contour map (see Figure 19) describes the flow system in the upper 15 feet of the aquifer. Ground water flows toward the lake, with the hydraulic gradient toward the lake approximately three percent over most of the shoreline. The flow system near Kalispell Creek shows ground water movement towards the creek as well as the lake; in the vicinity of the creek there is a general flattening of the gradient to approximately one percent.

Water level elevation data from deeper wells represent the aquifer at an average depth at about 70 feet below land surface (see Figure 20). At this elevation, the water level elevation in the deep portion of the aquifer is greater than in the shallow portion, demonstrating an upward hydraulic

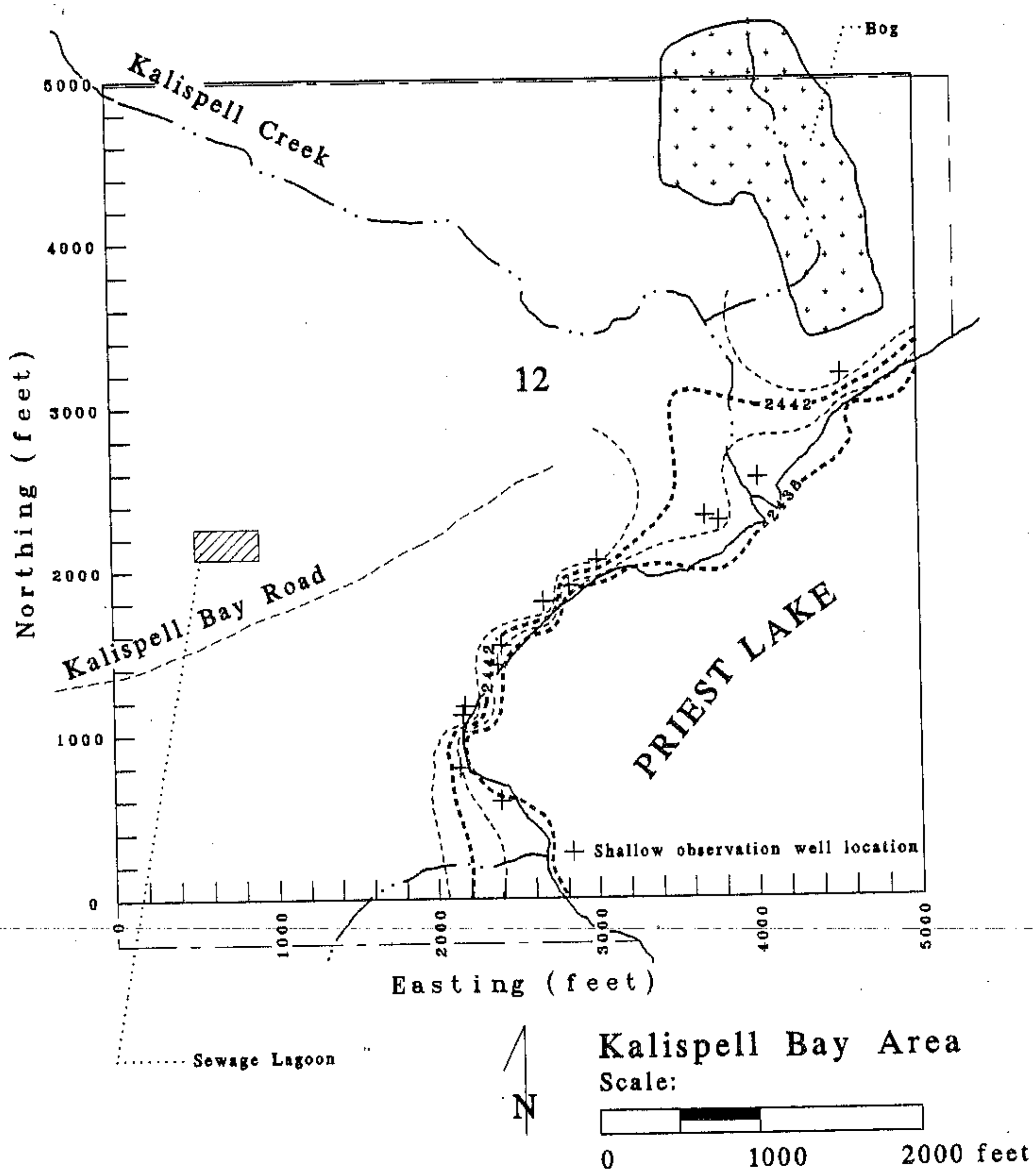

Figure 19. Water level elevation contour map for the shallow portion of the aquifer, Kalispell Bay study area.

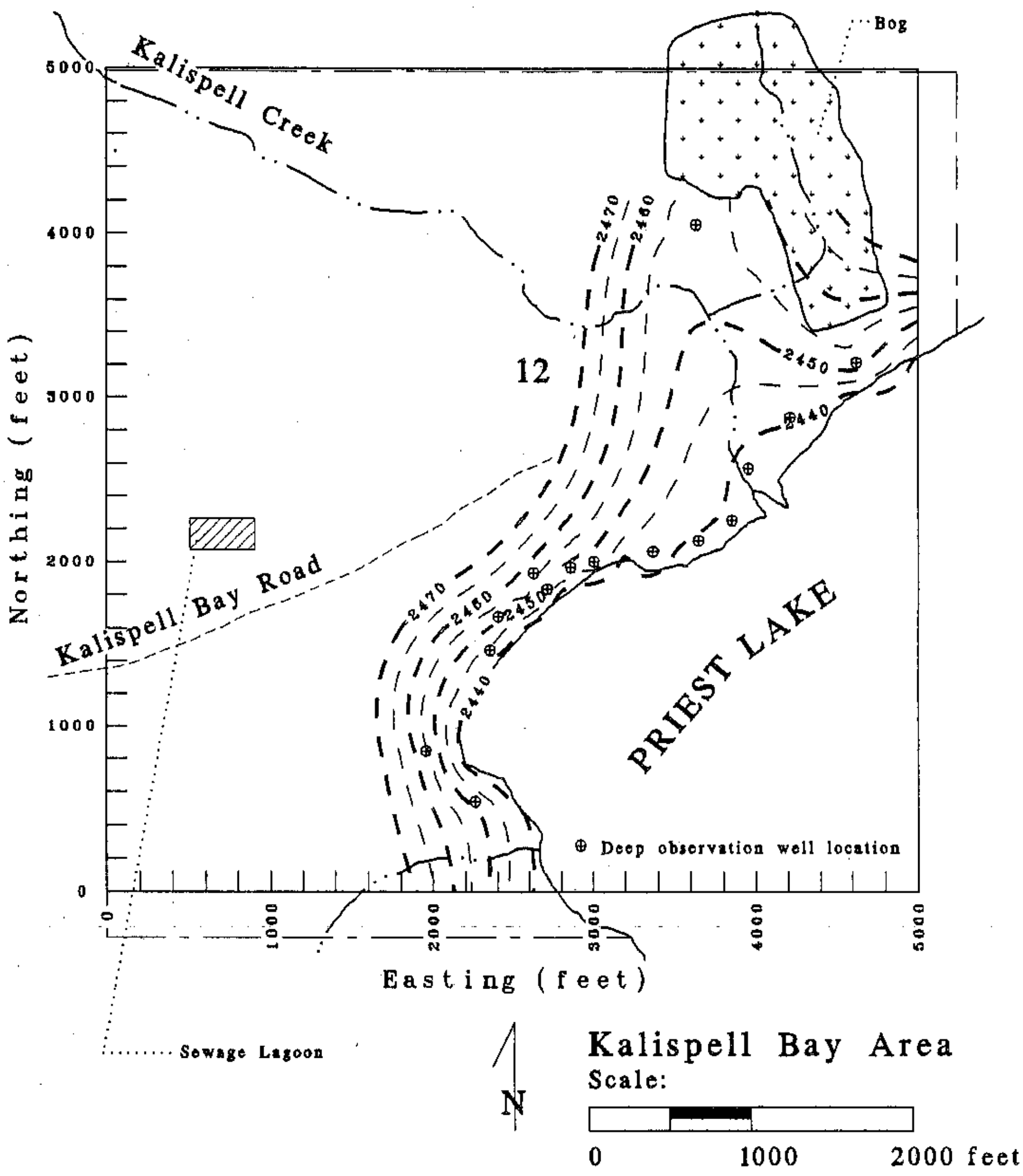

Figure 20. Water level elevation contour map for the deep portion of the aquifer, Kalispell Bay study area.

gradient in most of the area. In the area immediately surrounding Kalispell Creek the deep water levels are about the same to slightly less than the shallow water levels; very little vertical gradient is present in this area. The hydraulic gradient at an average elevation of 2380 feet MSL over most of the area is approximately five percent. This is greater than the gradient present in the overlying shallow portion of the aquifer as well as the three percent bedrock topographic gradient. In the area near Kalispell Creek, the gradient is about three percent, as the aquifer is influenced by Kalispell Creek.

Two possible hydrogeologic conceptual models are proposed to explained the upward hydraulic gradient in the area. The first is that the lower portion of the aquifer is encountering a zone of greatly reduced hydraulic conductivity upon contact with Priest Lake. This low hydraulic conductivity zone could be caused by the deposition of fine-grained sediments along the lake bottom throughout area of Kalispell Bay. Kalispell Bay is topographically flat over most of its area, except for a loss of 40 feet in elevation through an off-shore slope. Figure 7 shows a cross section depicting the study area to Kalispell Island. This relatively flat bay would allow for the collection of fine sediments, creating a zone of low hydraulic conductivity between the aquifer and lake.

The second model for producing the upward gradient is a decrease in aquifer thickness caused by a rise in basement rock surface elevation. The cross-section for Kalispell Bay (see Figure 7) suggests that under Priest Lake, the basement surface elevation changes to a six percent slope up and toward Kalispell Island. The aquifer thickness decreases dramatically corresponding with this rise in basement surface elevation. The aquifer is effectively truncated; this creates a no-flow boundary perpendicular to the direction of ground water flow. This no-flow boundary could increase the hydraulic head deeper in the aquifer, creating an upward gradient.

Two explanations are offered to explain the area where upward vertical gradient is absent. First, Kalispell Creek is most likely a recharge source during high streamflow periods. This surface recharge may negate the upward gradient found over the rest of the area. Second, the delta of coarser grained sediments associated with Kalispell Creek could form a zone of significantly higher vertical hydraulic conductivity. This would reduce the upward gradient in the delta area.

3.2.3 Estimation of ground water velocity and discharge into Priest Lake from the Kalispell Bay study area

The ground water velocity and discharge into the lake from the study area was estimated, utilizing data obtained from sediment analysis, geophysical investigations and the ground water flow gradients. Ground water velocity was estimated through using Darcy's Equation. The equation for the *average linear velocity* of ground water along a flowpath is:

$$V_x = -\frac{K}{n_e}\frac{dh}{dl}$$

where: V_x = average linear velocity in ft/d

K = hydraulic conductivity in ft/d

n_e = effective porosity

dh/dl = hydraulic gradient

An overall range of porosity for a coarse to fine sand is 20 to 50 percent (Fetter, 1994). The porosity of the two samples was tested in laboratory and found to be approximately 40 percent. This value was determined after the sediment had been disturbed. The disruption of packing would probably cause the porosity of the disturbed sediment to be greater than the porosity of the *in situ* sediment; therefore an estimate of porosity for the aquifers within the study area is 35 percent. Effective porosity for coarse grained sediments is nearly equivalent to the porosity. The effective porosity for the aquifer is estimated to be 30 percent.

Estimation of hydraulic conductivity for an aquifer is usually based on either single or multiple well aquifer tests. However, the small screen slot size (0.10 inch) of wells constructed for the project precluded pump or slug tests. The slot size of the screen was too small to allow for an effective stressing of the aquifer.

The hydraulic conductivity of the aquifer was estimated through grain size analysis of two sediment samples taken from the Kalispell Bay area. The Hazen and Kozeny-Carmen methods for estimating hydraulic conductivity from grain size were used (see Appendix B). Results for hydraulic conductivity from these methods are presented in Table 9.

Coarse to fine sands have a wide range of expected values for hydraulic conductivity: from 0.057 ft/d to 1,700 ft/d (Fetter, 1994). The hydraulic conductivity values predicted by the Hazen and Kozeny-Carmine methods fall into a narrow range. A minimum value of 90 ft/d and a maximum value of 130 ft/d were selected to provide a range of hydraulic conductivity for the velocity and discharge calculations.

A range of average linear ground water velocities for the Kalispell Bay area were obtained using the estimated values of K, n_e, and *dh/dl*.

A value of n_e= 0.30 was selected. The average *dh/dl* value was calculated to be -0.04 in the deeper portion and -0.02 in the shallow portion; this yields an overall average *dh/dl*

Table 9. Hydraulic conductivities as calculated by the Hazen and Kozeny-Carmen methods for Samples 1 and 2.

Sample Number	Hazen Method K (ft/d)	Kozeny-Carmen Method K (ft/d)
1	170	128
2	57	92

value of -0.03. The estimated ground water velocities are 9 ft/d for a K= 90 ft/d and 13 ft/d for a K= 130 ft/d. This gives an average estimated ground water flow velocity of 11 ft/d near the lake.

Darcy's Law was used to estimate the quantity of ground water discharge into Priest Lake from the Kalispell Bay study area. An aquifer cross-sectional area of 400,000 ft^2 was calculated. This area uses an aquifer length of approximately 4,000 ft, derived from the area geology (see Figure 3) and an average thickness open to the lake of approximately 100 feet, derived from cross-section KR-KR' (see Figure 7). Using the above values, minimum and maximum Q values were calculated. Minimum ground water discharge from Kalispell Bay was calculated to be 1,080,000 ft^3/d (9,000 acre·ft/yr), while maximum discharge was determined to be 1,560,000 ft^3/d (13,000 acre·ft/yr).

3.3 Ground water flow systems in the Granite Creek study area

3.3.1 Introduction

A set of 43 wells observation wells is used to describe the ground water elevation in the Granite Creek study area (see Table 10). The observation wells are spatially distributed along the shore of Priest Lake and consist of existing wells and wells constructed for this study (see Figure 21). Water levels were recorded from the observation wells over a 5 month period (see Table 11). From the 45 existing wells in the study area, 28 were selected as an observation subset for water level elevation data. Selection of the existing well subset was based on the same criteria described for the Kalispell Bay study area. Water level elevations were recorded for the months of July, August,

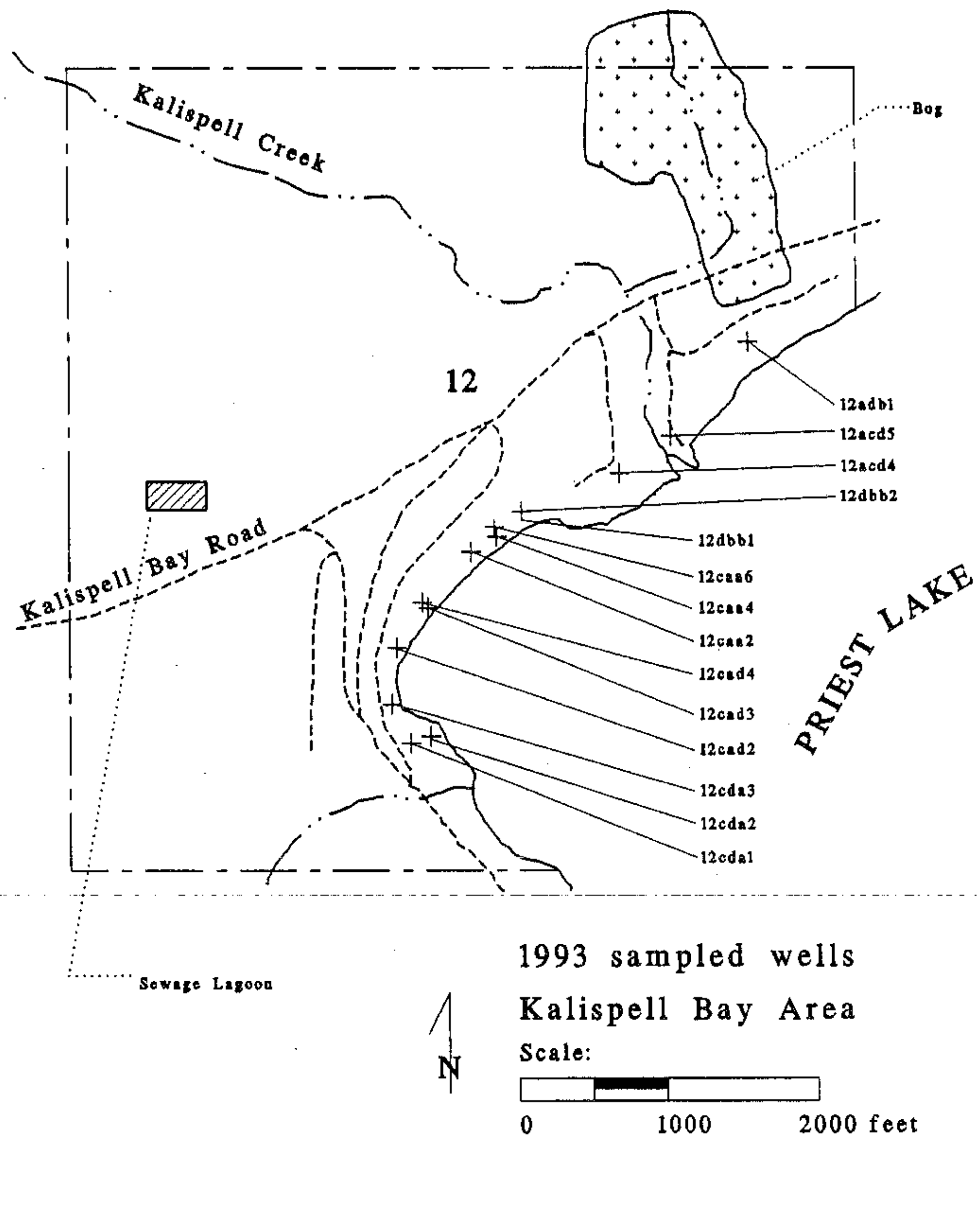

Figure 29. 1993 Kalispell Bay study area sampled wells.

presented in Table 22 for comparison. The glacial deposits aquifers include the aquifers of the Kalispell Bay and Granite Creek study area (Yee and Souza, 1987).

Reduction-oxidization potential (Eh) data (see Figure 30) were found to remain relatively stable over two sample runs. All values are within one standard deviation for both the overall and the monthly data with two exceptions; wells 12dbb1 and 12adb1 both display negative Eh values well outside the expected range. Well 12adb1 is located from a bog area; the organic debris from the bog may be creating an anaerobic plume in the ground water, causing a reducing environment in the well. No cause can be determined for the negative Eh found in well 12dbb1.

The pH data (see Figure 31) decrease over time in those wells located near Kalispell Creek. Wells distant from the creek show an increase in pH values from August to October and decrease from October to November. Only well 12cad4 exhibited pH data consistently greater than one standard deviation for both the overall and monthly statistics.

Table 22. Statistical summary of some key indicators for water quality in the glacial deposits aquifer, Panhandle Basin, Idaho (from Yee and Souza, 1987).

Constituent	n	Minimum	Maximum	Mean	Standard Deviation
pH	108	6.0	8.3	--	--
Temperature (°C)	122	3.0	20	9.3	2.6
Conductance (μS)	127	32	1050	231	149

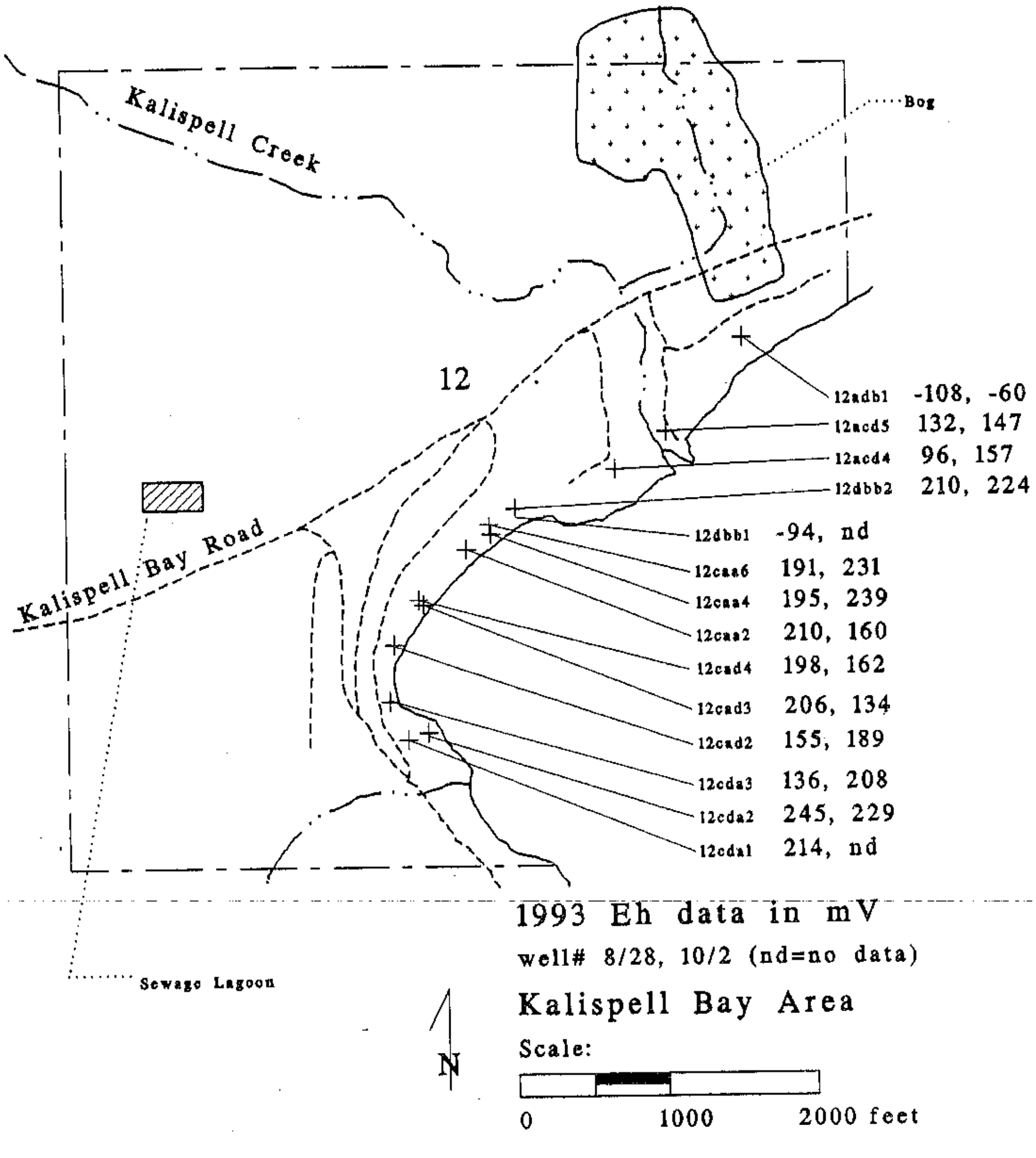

Figure 30. 1993 Eh data for the Kalispell Bay study area.

For temperature data (see Figure 32), the sampled wells show a general pattern of temperature increasing from August to October and decreasing from October to November. Wells 12cda2 and 12cda3 displayed consistently higher temperatures in August and October then other wells in the study area (with the exception of 12adb1), indicating a zone of warmer shallow ground water in this area.

The conductivity data (see Figure 33) displayed two major trends. Samples taken from wells 12cda1, 12cda2, and 12cda3, located in the southern portion of the study area, have consistently higher than average conductivity for all three sampling periods. The wells located adjacent to Kalispell Creek, 12acd4 and 12acd5, had conductivity values well below the mean and lower than the expected data range for August, October, and November. Conductivity values for all wells in the study area exceed the mean lake conductivity of 48 microsiemens (μS), particularly those wells located along the southern portion of the study area. Wells located near Kalispell Creek have conductivity values equivalent to the conductivity recorded in Kalispell Creek near its confluence with the lake (see Table 23). This supports positive interaction between the creek and the aquifer.

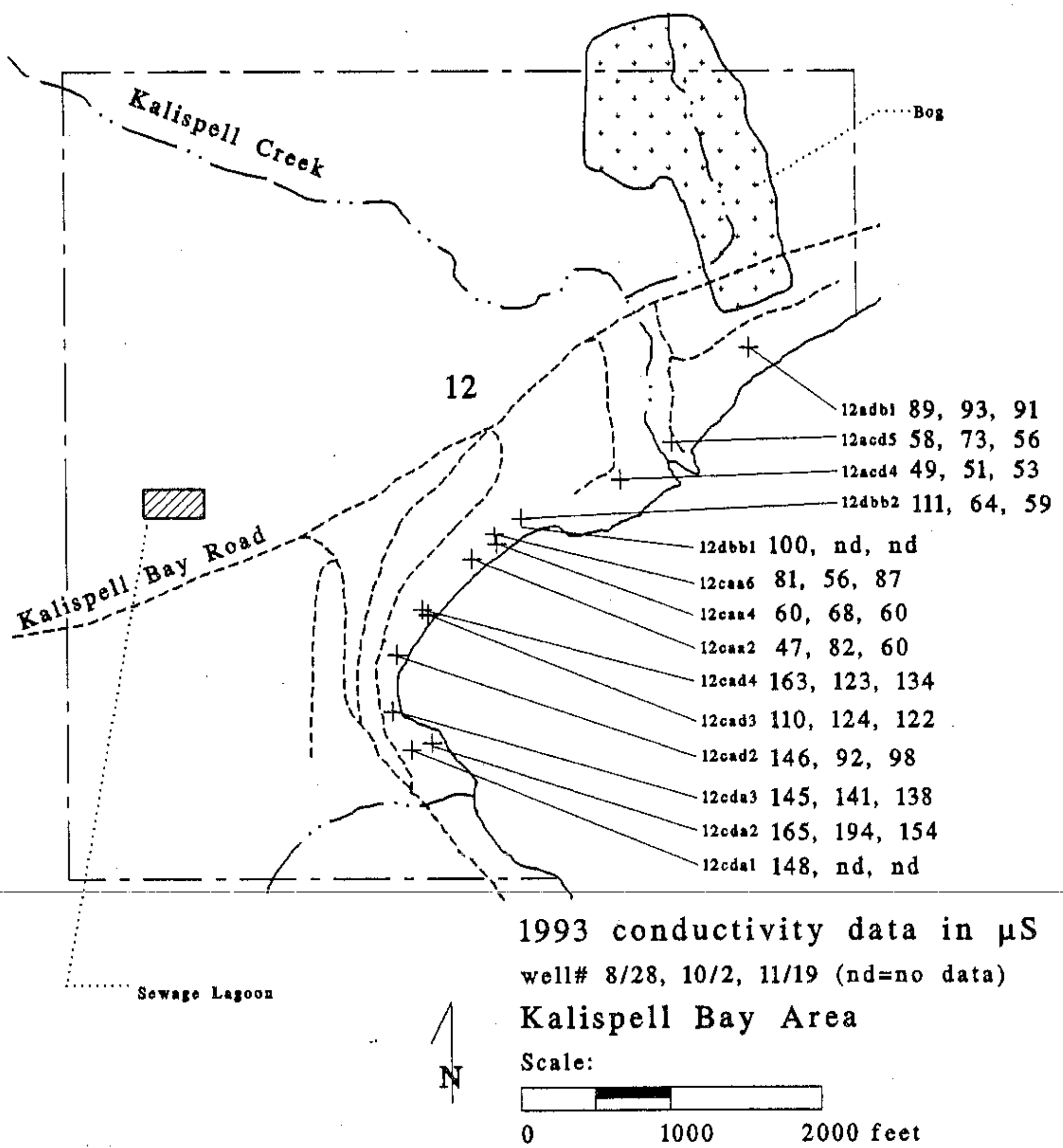

Figure 33. 1993 conductivity data for the Kalispell Bay study area.

The field parameters describe a spatially homogeneous ground water present in the Kalispell Bay study area. The ground waters appear to be equivalent with other aquifers in the surrounding area. Temporal changes in the character of the ground water are relatively small.

Table 23. Comparison of conductivity between Kalispell Creek and wells located near Kalispell Creek.

Date (1993)	Conductivity in µS		
	Kalispell Creek	**Well 12acd4**	**Well 12acd5**
July 20	52	--	--
August 28	--	49	58
October 2	--	51	73
October 20	57	--	--
November 19	53	53	56

4.2.3 Description of water chemistry

The cation-anion concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-} from all sampled wells with ion data are plotted using both Piper and Stiff diagrams to display the water chemistry of the Kalispell Bay study area. The ground water samples for the Kalispell Bay study area had charge balance errors of between one and 12 percent, with the majority between five to eight percent. Although a charge balance error of five percent is the generally excepted limit (Freeze and Cherry, 1979), charge balance errors of less than 20 percent may be used with some degree of confidence in low TDS water.

presence of fecal coliform, *E. coli*, through a positive or negative indication test.

Standards must be presented by which the relative amount of nutrients present in the ground water may be judged. The National Primary Drinking Water Standards is 10 mg/L for nitrate, 1 mg/L for nitrite, and one count per 100 mL for coliform bacteria (Fetter, 1993). There is no national drinking water standard for phosphorous.

The concentration of total nitrogen data (see Figure 36) for the Kalispell Bay study area ranges from 0.003 to 0.488 mg/L. The overall mean for the sampled period is 0.109 mg/L. Total nitrogen statistics for 84 analyses from the glacial deposits aquifer of the Idaho Panhandle basin (Yee and Souza, 1987) report a minimum value of 0.1 mg/L, a maximum value of 25 mg/L, a median value of 0.1 mg/L and a mean value of 0.7 mg/L with a standard deviation of 2.7 mg/L. The mean value for the Kalispell Bay study area is equivalent to the median value and well below the mean value of the regional aquifer. This implies that most of the wells in the study area have nitrogen values that are equivalent to or below the regional mean.

Total Kjeldahl Nitrogen (TKN), the sum of organic nitrogen and ammonia (Fetter, 1993), was measured occasionally for selected wells. In all wells but 12adb1, TKN was equal to or less than total nitrogen, indicating that almost all nitrogen was present as nitrate. In well 12adb1, the TKN

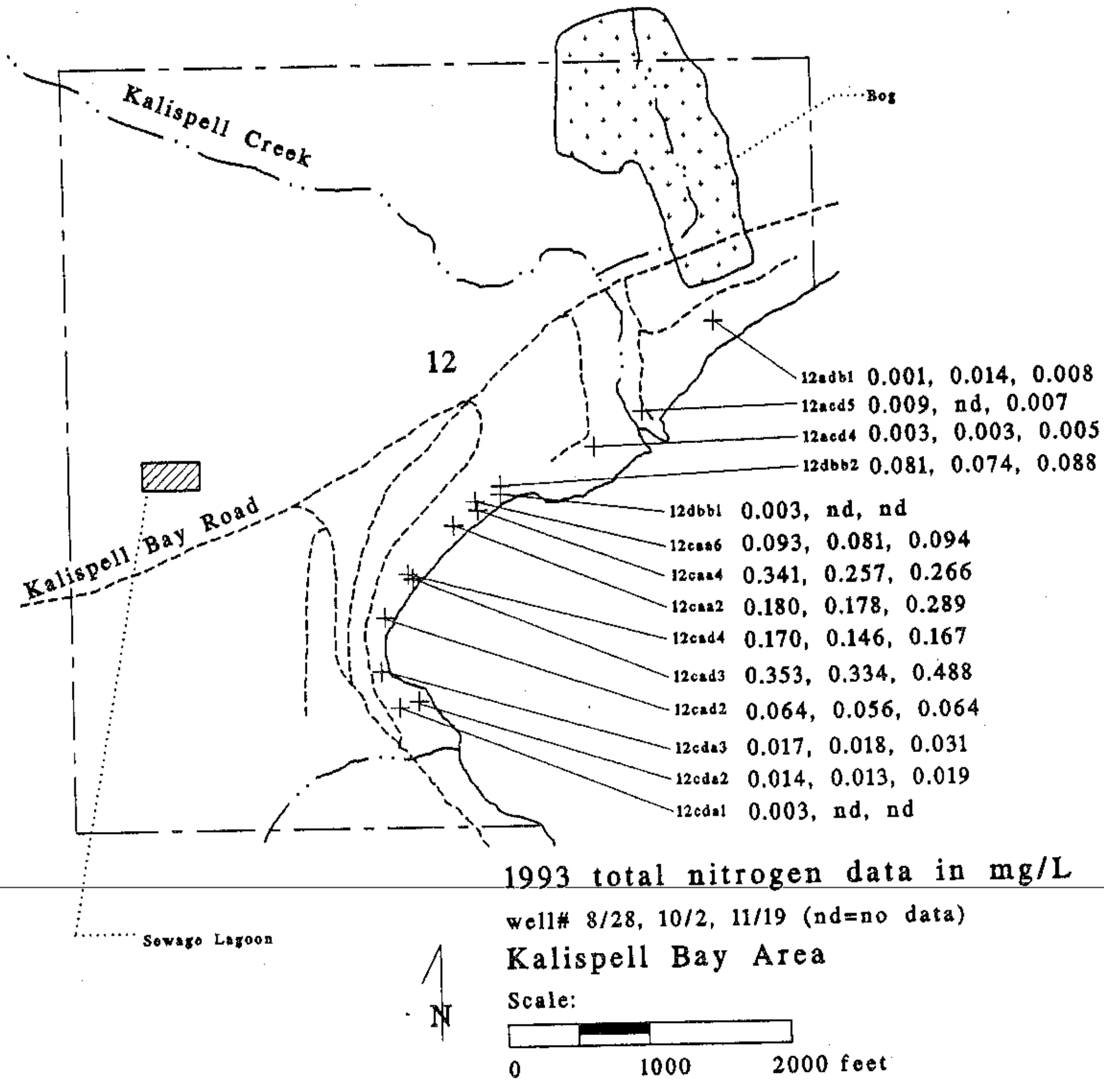

Figure 36. 1993 total nitrogen data for the Kalispell Bay study area.

concentration was much greater than the total nitrogen concentration, further indicating an anaerobic zone occurs near the well (Fetter, 1993).

All reported total phosphorous values for the study area were less than 0.5 mg/L (see Appendix C), with the highest value being 0.48 mg/L of total phosphorous recorded in August from well 12cad3. Seventeen analyses were conducted for total dissolved phosphorous (see Figure 37), with the overall mean calculated as 0.029 mg/L. All values reported for total dissolved phosphorous appear to fall below any reasonable background level.

The coliform data for the Kalispell Bay study area show wells 12cad2, 12cad4, 12acd5, and 12adb1, have significantly elevated coliform counts, between 93 and 1100 counts/100mL (see Figure 38). In addition, five wells, 12cda2, 12caa4, 12acd4, 12acd5, and 12adb1, tested positive for fecal coliform during either August or October, with 12adb1 testing positive for both months. Wells 12adb1, 12acd5, and possibly 12acd4 may be receiving their fecal coliform contamination from the swamp to the north of 12adb1. This swamp tested positive for fecal coliform. There does not appear to be any spatial correlation with an obvious fecal coliform source for the other positive wells.

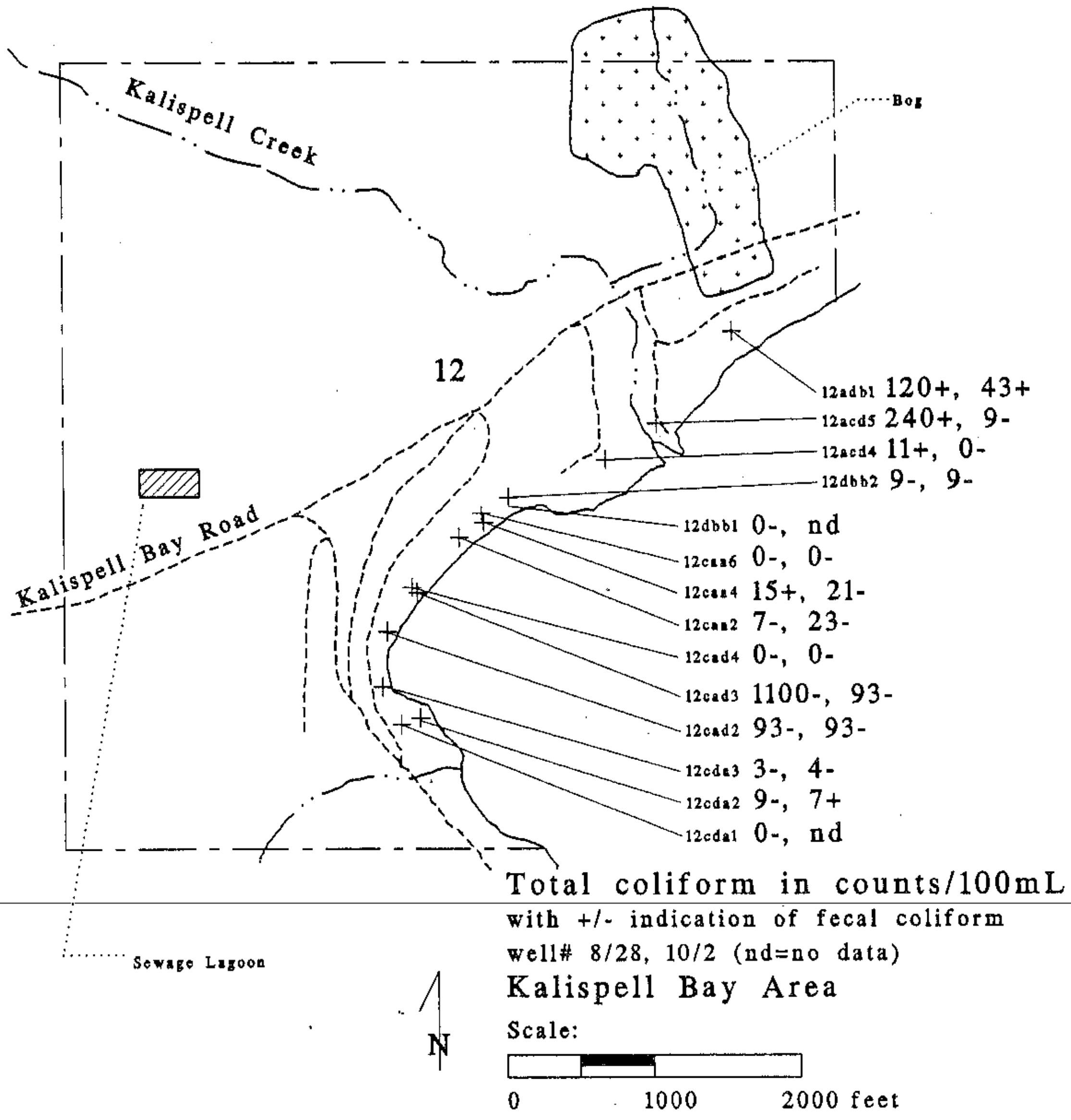

Figure 38. 1993 total coliform and fecal coliform data for the Kalispell Bay study area.

Well Number		12adb1				
Sample ID		PLK07				
Date		8/28/93	8/28/93	10/2/93	10/2/93	11/19/93
Laboratory		UI	IDHW	UI	IDHW	IDHW
Eh	(mV)	-108		-60		
pH		6.6		6.3		5.7
Temperature	(°C)	12.6		10.7		8.9
Conductivity	(µS)	89		93		91
Total P	(mg/L)					
Diss. Total P	(mg/L)					0.065
Ortho-P	(mg/L)					
Nitrate	(mg/L)		0.003		0.014	0.008
TKN	(mg/L)				2.69	0.95
TDS	(mg/L)		114		113	186
Alkalinity	(mg/L)		38		40	35
Ca	(mg/L)		9.6		10.5	9.4
Mg	(mg/L)		1.4		1.5	1.4
Na	(mg/L)		4.3		3.9	3.8
K	(mg/L)		1.5		1.1	1.2
Cl	(mg/L)		1.2		1.9	1.9
SO4	(mg/L)		2.5		2.5	
SiO2	(mg/L)		34		36	
Dissolved Fe	(mg/L)				7602	6185
NH3	(mg/L)	0.84		0.84		
DO	(mg/L)			7.7		
AODC	(Log)	5.921		5.959		
Coliform/100ml		120		43		
E. coli		1		1		
Water level MSL	(feet)	2446.6		2446.6		2446.6