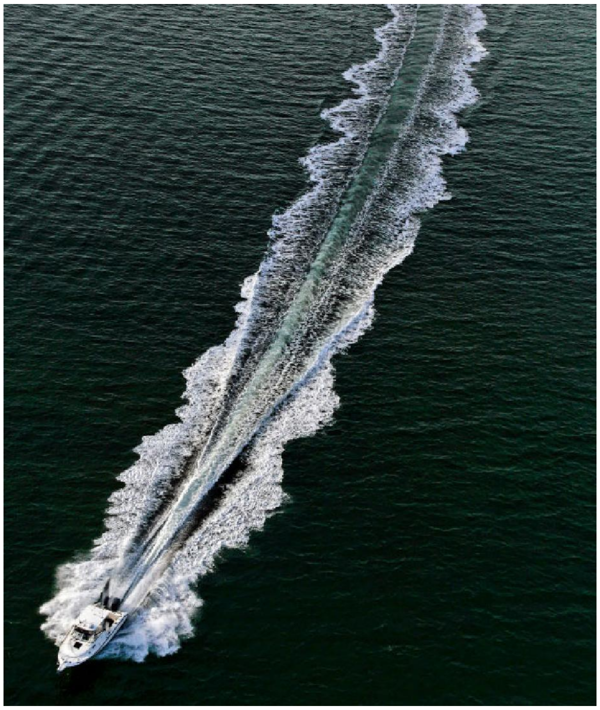
Kalamalka and Wood Lake

Boat Impact Study
On Source Waters



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March 2017

Ecoscape File No. 16-1796

ACKNOWLEDGEMENTS

This project would not have been realized without the assistance and contribution from the following individuals and organizations:

- Okanagan Collaborative Conservation Program
- Regional District of North Okanagan
- District of Coldstream
- District of Lake Country
- Okanagan Basin Water Board
- Okanagan and Similkameen Invasive Species Society

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Recommended Citation:

Schleppe, J., H. Larratt and R. Plewes 2016. Kalamalka and Wood Lake Boat Capacity Study on Water Sources. Ecoscape Environmental Consultants Ltd. Project File: 16-1796.

INFORMATION DISCLAIMER

The results contained in this report are based upon data collected during a single season inventory. Biological systems respond differently both in space and time. For this reason, the assumptions contained within the text are based upon field results, previously published material on the subject, and airphoto interpretation. The material in this report attempts to account for some of the variability between years and in space by using safe assumptions and a conservative approach. Data in this assessment was not analyzed statistically and no inferences about statistical significance are made if the word significant is used. Use of or reliance upon biological conclusions made in this report is the responsibility of the party using the information. Neither Ecoscape Environmental Consultants Ltd., the authors of this report or the Okanagan Collaborative Conservation Program (or their members) are liable for accidental mistakes, omissions, or errors made in preparation of this report because best attempts were made to verify the accuracy and completeness of data collected, analyzed, and presented.

EXECUTIVE SUMMARY

Recreation, either from local residents or from tourism, on the large lakes of the interior is an important industry, and has experienced rapid rates of growth in recent years. The incredible scenery and values received from these large lakes also includes necessary services, such as domestic water. The rapid growth rates on these large lakes increases risks to critical resources such as water delivery for our communities. This report is intended to consider these risks spatially, and support risk-related planning for Kalamalka and Wood lakes.

Kalamalka and Wood lakes are important water sources for residents, with Kalamalka Lake having the largest intakes. Each of these lakes have shallow littoral zones, with large shallow areas. Littoral zones are the areas of lakes that are highly productive and they usually occur in areas of less than 6 m depth where light can penetrate to the bottom. Recreation is known to actively occur in these areas and visual observation has suggested that sediments are disturbed. The main risk to water quality from all forms of powerboating recreation is related to either contaminants (pathogens, bacteria, hydrocarbons, metals) released during sediment re-suspension or from chemical spills, most frequently occurring during refueling, cleaning, or disposal of wastes

Balancing the drinking water resource with recreation, particularly motorized recreation, involves identifying the risks posed to the water resource, their possible amelioration, and identifying environmental degradation. We used physical data and a spatial model to quantify the risks and determine the areas of highest vulnerability on Wood and Kalamalka lakes. The data collected in this study suggest that boating recreation is capable of sediment re-suspension within shallow areas, most notably in the south and north ends of Kalamalka Lake. Further, this sediment can migrate towards municipal intakes under the right conditions. A range of bacterial, hydrocarbon and metal contaminants were detected in sediment samples and these can enter the water column following re-suspension. Given this, a model was created to identify the physical spaces around the municipal intakes that are more susceptible to mobilized sediments, increasing risks of an associated drinking water event. The data used in preparation of this spatial model was conservative, to ensure that focus was placed on addressing average use, versus a worst-case scenario. In the worst-case scenario, both lake perimeters and the drinking water intakes using them are at risk, particularly the shallow private intakes. Risks to environmental resources, such as spawning fish, wetlands, and nesting birds were also considered.

Based upon the data available, it is apparent that some areas around Kalamalka Lake at may be at or exceeding recreational carrying capacity during the high-use summer season. A carrying capacity is a multi-faceted threshold beyond which unacceptable consequences occur. Applied in this case, the identified threshold is the point when powerboating recreation can reasonably affect either recreational safe use, and/or environmental or water quality resources. The assessment identified localized areas where power vessels may be exceeding capacity, and the risks that these vessels have depending upon where they choose to recreate. This data is best viewed graphically, but key areas identified as areas of concern occur in the north and south ends of

Kalamalka Lake, and along the Oyama Canal. In these areas, the fine sediments are easily mobilized in shallow waters. The areas around Kalamalka Lake Provincial Park were also busy, possibly exceeding capacity at peak use, but are less concerning like other rocky areas on the eastern shoreline. In these sensitive areas, sediment contaminants that exceed guidelines were detected. Finally, while boat densities in these high risk areas did not appear to exceed capacity. The carrying capacity analysis could not address key commuter corridors because time spent in transition to and from a location is often short lived, and it is noted here that these key areas are found on both the south end of Kalamalka Lake and the Oyama Canal are good examples.

To address high risk areas, a set of recommendations focused on trying to mitigate powerboat impacts are presented. These recommendations focus on using signage, no-wake zones and designated commuter corridors to ensure that recreational pursuits are done in a way that reduces risks to drinking water intakes and harm to the littoral areas of Kalamalka and Wood lakes.

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1.0 INTRODUCTION

1.1 Power Boat Recreation

The lakes of the central and north Okanagan are crucial for economic, recreational, social, and environmental services such as water supply. With ongoing growth in the region, risks to these key resources are increasing. Main stem lakes such as Kalamalka and Wood, with their large littoral zones, are at greatest risk with increasing population pressures. There has been little work done that considers the capacity these lakes have for recreational use balanced against water supply requirements. At some point, either for safety or environmental reasons, these lakes will reach a point when safe use, or use within a tolerated level of risk, exceeds their capacity. It is clear from literature reviews, that the environmental effects from powerboating can often be underestimated (Mosisch and Arthington, 1998).

The current and projected use of Kalamalka and Wood lakes for powered water craft recreation can have adverse impacts on water quality at domestic water intakes. Approximately 8000 boats are owned in the Greater Vernon area, with a projected increase of 2000 boats in the near future (GDH et al 2011). This estimate does not consider boats owned in the central Okanagan areas such as Kelowna or West Kelowna, which can also utilize these lakes. Additionally, there is an expected increase in demand for boating facilities in both the north and central Okanagan over the coming years to address the increasing recreational demands. To this point, we are unaware of any formal considerations of the capacity of these lakes despite the expected increase in demands.

Powered vessels are the primary type of craft found on these lakes, followed by manually powered boats using oars or paddles (GDH et al 2011). Boating styles and behaviors vary by individual, as does demand for supporting facilities such as boat launches and marinas (GDH et al. 2011). Of those surveyed, 71% own a motor boat, with 37% using powered vessels under 15 feet and 45% using vessels greater than 15 feet. Unfortunately, the group that represents 45% are most likely to adversely impact water quality at a domestic intake for a variety of reasons such as increased prop scour due to boat draft or boat design and increased wake damage.

1.2 Power Boat Impacts

Power boats create turbulence that can reach several meters into the water column and increase turbidity, with turbulence increasing as water displacement or motor size increases. The potential for substrate disturbance is greatest before boats reach planing speed. Wakeboard/wakesurf boats do not reach planing speed, and have ballast and hulls designed to increase wake height to 0.5 – 1.2 m or more. For reference, researchers found that boat wakes of less than 12 cm in height did not re-suspend sediment (Asplund, 2000). A wave that is 25 cm high is four times more destructive than a 12.5 cm wave. Further, 62.5 cm high waves are 25 times more destructive than waves of <12 cm high (Envi Canada 2005). Waves under 12 cm in height are created by boats operating at speeds under 10 km/h – a speed that is generally considered reasonable when operating within 30 m of shore. Additionally, the angle of these wake style vessels directs more turbulence toward the lake bottom. Therefore, large wakeboard/wakesurf boat wakes can have a greater negative impact than other powerboat designs.

Wake damage is also affected by the angle to the shoreline and “turning wakes”. Wakes are reinforced if the boat doubles back on its own wake, a common practice in wake surfing. The wave energy from boat wakes exerts a cumulative effect from combined wave trains from multiple boats. In our experience, there are far more high energy boat wakes striking shore than wind waves along the east and west shores of both lakes.

Turbulence from larger boats with large wakes, or the waves resulting from being under power, is particularly concerning given the fine sediments in the littoral zones of these two lakes. The shallow terraces of Kalamalka Lake are covered with more than 50 cm of fine marl calcite (Larratt 2001), while Wood Lake sediments consist mostly of silts with a smaller marl component. In terms of sediment particle size, these fine sediments are 6% sand, 70% silt and 24% clay + marl (Larratt, 2001). They are easily re-suspended into the water column in the shallows primarily through wind-driven wave action and seiches, and boat-generated vertical turbulence and wakes.

The impacts of prop turbulence and boat wakes on water intakes are affected by boat use and wind-driven water currents. As recreational pursuits increase on these lakes, the associated risks of powerboating also increase as a function of boat densities. Recreational boaters undertaking recreational activity tend to find appropriate space to conduct their pursuits. As density increases, boaters will seek an open area to recreate, with more boats utilizing perimeter areas such as the littoral zones. If boating occurs in shallow waters near intakes, risk to the domestic water sources is greater than if recreational activities occur at greater distances or outside of these more vulnerable zones.

1.3 Sediment Resuspension and Impacts on Intakes

Based on our experience in Wood and Kalamalka lakes, spills on the lake (or runoff from a spill on land via a storm discharge) and sediment disturbance are the two factors that have the potential to contaminate water to the greatest extent. Since these lake sediments are known to contain bacteria, heavy metals, pesticide residuals and hydrocarbons at refueling facilities (Larratt, 2001; Walker et al. 1993), once mobilized, they increase risks to a water intake. The small particle size of these marl substrates is especially concerning because they are so easily mobilized. Mobilized and suspended sediments in the water column take time to settle, with smaller particles taking longer. Sediments taken from water samples collected from these lakes showed that sediments can be mobilized upward by several meters above the lake bed (Larratt, 2005). Mobilized substrates can have a direct effect on an intake either through uptake of contaminants or by reducing the effectiveness of treatment through increased turbidity.

Bacteria and viruses occur at the highest concentrations in the upper few mm of sediment, which is the layer most susceptible to resuspension by turbulence (Grimes, 1980; Hagland et al, 2003). Studies have shown that lake sediments allow pathogenic bacteria to survive for several months thus, resuspension and human ingestion is a real possibility, particularly considering the reduction in treatment efficiency caused by turbidity from mobilized sediments (Burton et al., 1987 Christensen et al 2003).

Sediment plumes of contaminants can travel from disturbed areas to intakes following prevailing water currents, where concentrations gradually dilute from the point of origin. Risks to water quality are based upon numerous factors including the location of activities, boat densities and type, substrate type and potential contaminant loads of those substrates, and water depth. Another factor that warrants consideration include erosion resulting from large wakes, which poses both a significant environmental risk and a potential source water risk through sediment plumes.

1.4 Project Objectives

The objectives of this project to:

- To investigate the long-term potential threats from boating activity on lake source water protection for the municipal and domestic intakes on Kalamalka Lake;
- Understand the spatial distribution of boating activity using existing information to understand where primary recreational pursuits are occurring in relation to water intakes;
- Understand the spatial location of key risk areas based upon environmental factors including substrate type and proximity to source water intakes;
- Understand what are key factors that increase risk to source water intakes, such as sediment disruption, spills, marina facilities, etc. and identify key pathways or mechanisms that could result in contamination at the point of intake;
- Understand what types of boating activities pose the greatest risks based upon vessel types, sizes, and primary areas of use on both Kalamalka and Wood lakes.

2.0 METHODS

Data was collected to inform a spatial model that was developed for this project to address these key concerns on Kalamalka and Wood lakes. A bathymetric survey with 1 m contour resolution of the shallow ends of Kalamalka Lake and the entirety of Wood Lake were compiled in 2016 for this project by R. Novak. The spatial model uses point count boat density data to calibrate a model of lake utilization for recreation on the lakes. A substrate layer with data on contaminant loads was added to the data set, and when coupled with prevailing current patterns, allowed determination of the potential areas of higher risk to be determined spatially. The model attempts to estimate the likelihood that an event will occur for a variety of different source water risks, which were derived from the Source Assessments developed for source water intakes on Kalamalka and Wood Lake (Larratt, 2010). An estimate of environmental risk was also developed, which utilized the same boat density data, and key environmental data including the Foreshore Inventory and Mapping, and Provincial data for shore spawning Kokanee. The intent of this model is not to predict all factors that may lead up to an event, such as appropriate wind conditions, wave action, time of year, or other factors. Rather, the point was to identify were risks originate from, under the right conditions.

2.1 Background Overview

The mechanisms by which boat wakes can cause lakebed sediment suspension are based upon numerous factors, and for factors related to the vessels themselves, key criteria include: 1) Size of the prop, which affects the size of the prop wash flow and turbulence 2) Draft or depth of the hull, which is increased by ballast tanks and affects the direction of the prop wash, 3) Diameter and RPM's of the propeller, and 4) Speed of the vessel. This list highlights the complexities of factors affecting the velocity and direction of water from a boat propeller, whcih can all affect lakebed sediment mobilization. Key information to understand from this is:

1) As vessel speed increases, the velocity of propeller wash increases until a boat planes. At this point both wake height and water turbulence decreases; and,

2) Boat draft has the potential to affect sediment disruption because more power is needed to move the vessel and the direction of the thrust is at a sharper angle, typically towards the lakebed.

Other key factors that affect sediment mobilization are water depth and sediment composition. For water depth, a paper by Beachler and Hill (2003) concluded that for sandy lakebed sediments, depths of 2.75 m were the approximate depth upon which most power craft had a significantly reduced potential to influence lake bed sediments. For silty sediments with a grain size of 50 microns, the depth of boat influence increases to 4.6 m. Marl sediments are finer than silt (as small as 1.1 microns, the size of small bacteria) and are predicted to be mobilized by boat turbulence at depths of at least 5 m (Beachler and Hill 2003).

From our experience working on these lakes, it is easy to disturb the sediment in the > 1.5 m shallows under moderate acceleration in a 14 ft. aluminum fishing boat with 9.9 hp outboard. This is corroborated by aerial imagery from Kalamalka Lake, where "boat tracks" are evident from imagery obtained from this assessment and Google Earth to depths between 2 to 3 m (Figure 1).

Figure 1: Aerial imagery obtained as part of this study and through Google Earth that documents the locations or "boat trails" of sediment disturbance.

This background information provides key data allowing us to conservatively estimate that at depths less than 3 m in both Kalamalka and Wood Lake, there is potential for boat wakes to suspend and mobilize sediments. The 3m depth chosen for this study was selected because it is conservative, especially in Kalamalka Lake with its fine marl sediments that are prone to sediment disruption from boats. This does not include the impacts of large wakes crashing onshore, causing erosion and sediment plumes that can travel into deeper water

2.2 Water Depths and Bathymetry

Bathymetry data was collected for the north and south regions of Kalamalka and Wood Lake by Raphael Novak using side scanning sonar. The data collected was subsequently modelled, using GIS to develop a contour map, with a focus on shallow zones. Deep water zones were interpolated from historical contour maps obtained from the Ministry of Forests, Lands, and Natural Resource Operations online.

2.3 Sediment Collection

Sediment traps were deployed at 4 locations for a period of 70 days during the peak boating period in the summer (July 29 – Oct 7, 2016). Each location contained 2 sediment traps. Traps were collected and analyzed for total volatile solids (a measure of organic content) and dry weight (a measure of total mass) by CARO Analytical.

Table 1: Sediment trap locations

Location Name	Latitude	Longitude	Depth (m)
Kal S Shallow	50.116370°	-119.380150°	3
Kal S Deep	50.117260°	-119.373350°	24
Kal N Shallow	50.227040°	-119.266960°	14
Kal N Deep	50.227220°	-119.274430°	23

Sediment cores and Ekman dredge sediment samples were collected at 9 sites on three dates (Oct 7 and 26 for Kal Lake and Dec 5 for Wood Lake) and were analyzed for total metals, *E.coli*, and hydrocarbon contamination by CARO Analytical.

Location Name	Latitude	Longitude	Depth (m)	Total Metals	Bacteria	Hydro-carbons
Kal S Shallow	50.116370°	-119.380150°	3	X	X	
Kal S Deep	50.117260°	-119.373350°	24	X	X	
Kal N Shallow	50.227040°	-119.266960°	14	X	X	
Kal N Deep	50.227220°	-119.274430°	23	X	X	
Oyama Channel	50.111204°	-119.382382°	0.5	X		X
Kal South Marina	50.112287°	-119.383042°	1	X		X
Kal North Boat Launch	50.228415°	-119.265018°	1	X		X
Wood South Marina	50.052149°	-119.409193°	1.5	X		X
Wood North Boat Launch	50.104650°	-119.376656°	14	X		

Table 2: Sediment sample locations and contaminants analysed

2.3.1 Sediment Fall Tests:

Bench tests of sediment fall rates were performed to determine how quickly water clarity would return after a sediment disturbance. Tests were conducted in 1L brewer's flasks (35 cm deep; 6.5 cm diameter) using 10 ml of sediment collected from 6 sites (Kalamalka N Shallow/Deep and Kalamalka S Shallow/Deep; Wood S Marina and Wood N deep). The time required for the upper water column to become clear of sediment and for the entire column to fully clear of cloudiness were recorded. In some cases, samples remained permanently cloudy even after many days of settling. The sediment fall tests were repeated multiple times for accuracy.

2.3.2 Bacteria Fall Tests:

Bench tests of bacteria fall rates were performed to determine how quickly viable bacteria would settle out of the water column following a sediment disturbance. Bacterial fall tests were conducted at lake temperatures (10 – 12^{o}C) using the bulk samples that were a composite of the upper 15 cm of sediments. These tests were conducted in 1L brewer's flasks using sediment collected from 4 sites (Kalamalka N Shallow/Deep and Kalamalka S Shallow/Deep). Samples were collected 1 hour and 72 hours after a simulated sediment disturbance and analyzed for total coliforms and *E.coli* by CARO Analytical.

2.4 Lake Current Data Collection

Currents in Kalamalka and Wood Lakes are variable and are influenced by wind. Horizontal currents are the strongest in the top 5 m of most lakes and we found that here. Drogues were used on 3 occasions in Kalamalka Lake adjacent to intakes and at several depths (5m 10m 20m 30m S; 5m 10m 20m N) and on five occasions in the shallow south end of Kalamalka Lake (0.5m 1m). Each drogue was tracked using GPS for several hours.

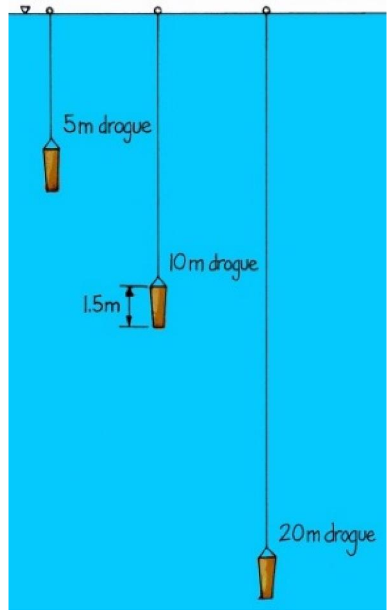


Figure 2: Schematic of Drogues

2.5 Boat Density Spatial Model and Calibration

A boat density model was designed to accurately represent the spatial distribution of boats on a busy day on Kalamalka and Wood lakes, with a focus on powered watercraft. The model assumed that people recreating in boats do not typically utilize areas within 60 m of the shoreline for active recreation or areas occupied by larger marinas, although these areas are often used for commuting. The boat density model used boat launch data, marina data, and boat count data. The boat count data was collected in August and September 2016 by staff from the Regional District North Okanagan, District of Lake Country, and Okanagan and Similkameen Invasive Plant Species Society)OASISS).

Six public boat launches were identified along the shoreline of Kalamalka Lake, whereas 1 public boat launch was identified along Wood Lake. Each boat launch was weighted to represent the estimated usage, with boat launches heavily used assigned a higher weight (e.g., Kalavista Boat Launch in Coldstream) than launches with lower utilization (GDH Solutions 2008/2011). The weight represented how busy the boat launch was relative to other boat launches, and ranged from 0.5 to2. Data from the Boat Launch Study on Kalamalka Lake and Okanagan Lake and the RDCO Major Lakes Recreational Marine Facilities Study was used to estimate the weight of each boat launch (GDH Solutions 2008/2011). Boat launches that have a weight of 2 were assumed to launch approximately 4 times as many boats as boat launches with a weight of 0.5. For modelling purposes, it was assumed that an average boat launch had 20 boats launched from it, meaning a busy boat launch had 40 boats launched from it on any given day.

There were 2 marinas identified in Wood Lake and 6 marinas identified in Kalamalka Lake. The number of slips for each marina was obtained from existing data or through air photo interpretation. For modelling purposes, it was assumed that there was a 20% lake usage rate from the marinas, meaning the number of boats was determined to be 20% of a total number of marina slips.

For the boat density model, the total number of boats on the lake on a peak day was calculated from only the marinas and boat launches, and it assumed that boats were not originating from private docks on the lake. A spatial model was then used to determine the distribution of these boats on the lakes. For this spatial model of boat density, it was assumed that 50% of boats travelled up to 4 km and the remaining 50% travelled up to 12 km from their point of origin (marina or boat launch). Two distances were used because it was assumed that boats were more likely to be in the area close to a boat launch than further away. It is also highly probable that boats come and go from their point of origin, meaning that many boats remain close to where they originated for a reasonable portion of their time on the water. The model did not account for hourly variation in data because insufficient data exists. Thus, the model of boat distribution is considered typical of a peak utilization, which likely occurs between noon and 3 PM usually on weekends.

The spatial boat density model was calibrated using boat count data from this assessment, which allowed adjustments to be made in GIS. The sum of all boat count data within a 500 m by 500 m cell was broken up into the following categories: 1) less than or equal to 4 boats; 2) greater than 4 boats and less than or equal to 10 boats; 3) greater than 10 boats and less than or equal to 24 boats; and 4) greater than 24 boats. These categories were assigned weightings from 0.5-2. These weightings were then used to adjust the spatial boat density model and better represent the distribution of boats observed on the lake, based upon key areas where boats were likely to occur (versus assuming an even distribution).

The boat density maps focused on where a boat originated from, how many boats utilized Kalamalka and Wood lakes on busy days, and areas where they tended to travel. To facilitate the model, we used estimates about how far they would travel.

Boat utilization was categorized into four categories within a given area. Each area occurred in a grid sized at 500 m by 500 m (25 ha):

1) Low density was treated as having less than 1 boat per cell;
2) Moderate density was treated as having 1 boat per cell;
3) High density was 1 to 3 boats per cell; and,
4) Very High density was treated as greater than 3 boats per cell.

While the number of boats per grid cell may seem low, the area was chosen because it represents an approximation of the area needed for active recreation, where some boats are active and some are at idle, given that the literature provides a very wide range of values in the area that boats need to safely recreate. The value of 20 acres per boat was chosen as a reasonable estimate, and it is exceeded if there are 4 boats in any given cell.

If cells were empty for all days the boat counts were conducted, the cell was assigned a weighting of 0, because it was assumed that boats only commuted through, versus recreated in these spaces. As boat density increases, the utilization of these areas (i.e. probability) would increase. For the modelled boat densities, boats that were found in a cell with a weighting value of 0 were moved to the neighboring cell with the highest weighting value. If a cell that had a weighting of 0.5 had a modelled boat density of more than 1 boat, the additional boats were assigned to the neighboring cell with the highest weighting. The final boat density model predicated 208 boats would be distributed throughout Kalamalka and Wood lakes on a busy day. This number is reasonable, given that there were a total of 301 boats observed on August 20, 2016. This was the peak boating day identified from the boat count data, and is assumed to be a high estimate because numerous counts, by different observers at different times were used to determine this total.

2.5.1 Carrying Capacity

Modelled boat densities were used to determine if a given grid cell exceeded the carrying capacity, assuming that 20 acres/boat are needed to actively recreate. This value corresponds to literature values of carrying capacities for primarily motorized uses. (Rajan *et al.,* 2011), where the area required by boats increases with the type of recreational activity occurring. For example, fishing boats require less space than boats used for wake boarding or water skiing. A full carrying capacity analysis would require more information regarding the different activities and relative distribution of those activities at any given time (i.e., at any time, how many boats are actively recreating, fishing, or sitting passively), all of which is extremely complex, and likely has many interdependencies and interactions between boaters. This analysis highlights areas of the lake where carrying capacities are more likely to be reached at any given time based upon observational data over the summer of 2016.

2.6.1 Likelihood Models

Criteria were used to determine the likelihood of recreational activity each cell (5m X 5m) within Kalamalka and Wood lakes having a negative effect on a source water intake or high value habitat. The cell size for this model was reduced to ensure it better represented the scale of data available, ensuring a more accurate representation of risk. The main focus of the likelihood index was the hazard of sediment re-suspension. Sediment re-suspension poses a risk for source water intakes and high value habitat because it can mobilize contaminants such as polycyclic aromatic hydrocarbons (PAH) and bacteria. Also, it can cause elevated turbidity levels which are a concern both for the source water intake and for fish. The criteria were based on previous studies, collected data, and professional judgement. The likelihood levels that were used are the same ones used in the Source Assessment of the North Kalamalka and South Kalamalka Lake Intake (Larratt 2010, 2011, Table 3).

Table 3: Likelihood Levels Used in likelihood index calculations		
Likelihood Level	**Descriptor**	**Probability of occurrence**
A	Almost Certain	>90%
B	Likely	70-90%
C	Possible	31-70%
D	Unlikely	10-30%
E	Rare	<10%

2.6.1 Source Water Protection Likelihood Model

The likelihood of a sediment disturbance event affecting a source water intake is primarily a function of the physical properties of the lake sediment, physical lake conditions, distance from the water intake, and the potential for recreational use to act as an agent mobilizing sediments. Likelihoods for lake depth, distance to source water, substrates, and recreation were based on the criteria listed in Tables 4, 5 & 7.

The development of a likelihood index considered the physical properties of sediment by creating general substrate polygons that split areas by dominance of fine (sands, silts, clays, and marl) or coarse substrates (gravel, cobble, boulder, and bedrock). Areas expected to have elevated concentrations of contaminants were also quantified based on sediment core data and professional judgement to determine an estimate of the approximate spatial extent. The settling time of the substrates were also considered using data from the fall tests.

Table 4: Criteria Used to Determine Substrate Likelihood		
Likelihood Level	**Substrate Criteria 1**	**Substrate Criteria 2**
A	Percent Fines Area >50% & Elevated Sediment	
B	Percent Fines Area <=50% & Percent Fines Area >25% & Elevated Sediment	Percent Fines Area >50% & Non-Elevated Sediment
C	Percent Fines Area <=25% & Percent Fines Area >10% & Elevated Sediment	(Percent Fines Area <=50% & Percent Fines Area >25% & Non-Elevated Sediment
D	Percent Fines Area <=10% & Percent Fines Area >0% & Elevated Sediment	Percent Fines Area <=25% & Percent Fines Area >10% & Non-Elevated Sediment
E	Percent Fines Area =0% & Elevated Sediment	Percent Fines Area <=10% & Non-Elevated Sediment

The integration of lake depth and current data collected in this assessment was used as surrogates for the physical lake condition, to understand how far mobilized sediment may travel during typical wind events on the lakes. The lakes were split into a shallow (3 m depth contour) and deep zones (>3m depth) using available bathymetry data. Bathymetry data was not available for the middle of Kalamalka Lake so professional judgement and aerial photo interpretation was used, relying upon the coarse, historical bathymetry maps publicly available from the Province. The drogue data collected as part of this study was used to estimate the average and maximum speed that a disturbed particle or contaminant associated with these particles could travel. The maximum speed was determined from the average of the daily maximum speeds of the drogues deployed at 5 m depth. The average of the daily mean speed of the drogue at 5 m depth was used as the average speed. Average and maximum speeds for Wood Lake were estimated because there was no drogue data available for Wood Lake. Lake currents are extremely complex and these data do not reflect the full complexities of potential current patterns. Rather, the intent was to understand how far and how fast liberated sediments may move during typical events.

Table 5: Criteria Used to Determine the Depth Likelihood

Likelihood Level	Depth Criteria
A	Percent Shallow Area >30%
B	Percent Shallow Area <=30% & Percent Shallow Area >0%
C	
D	
E	Percent Shallow Area =0%

The influence of recreational use on the likelihood of a sediment disturbance was quantified by considering a combination of predicted powerboat densities, and the proximity to marinas, boat launches, and public beaches. Beaches were categorized according to use (low or high). The size and use of the beach determined the likelihood of swimmers triggering a sediment disturbance. For example, a large high-use beach would have a greater likelihood of triggering a sediment disturbance compared to a small beach access. The proximity of marinas and boat launches was also considered because these areas are high traffic where boats are frequently travelling at speeds that are below their planing speed, meaning the increased potential for sediment re-suspension. Areas with high predicted boat densities are also thought to increase the likelihood of a sediment disturbance because of increased utilization of the area.

Table 6: Criteria Used to Determine Recreational Activity Likelihood						
Likelihood Level	**Distance to High Use Beach (m)**	**Distance to Low Use Beach (m)**	**Distance to Beach Access (m)**	**Distance to Marina (m)**	**Distance to Boat Launch (m)**	**Boat Density (boats)**
A	Distance <25			Distance <100	Distance <101	Boats >3
B	Distance >=25 & Distance <300	Distance <25	Distance <25	Distance >=100 & Distance <500	Distance >=100 & Distance <500	Boats <=3 & boats >2
C	Distance >= 500 & Distance <1000	Distance >=25 & Distance<500	Distance >=25 & Distance <500	Distance >=500 & Distance <1000	Distance >=500 & Distance <1000	Boats <=2 & boats >1
D	Distance >=1000 & Distance <2000	Distance >=500 & Distance <1000	Distance >=500 & Distance <1000	Distance >=1000 & Distance <2000	Distance >=1000 & Distance <2000	Boats <=1 & boats >0
E	Distance >=2000	Distance >=1000	Distance >=1000	Distance >=2000	Distance >=2000	Boats =0

The distance of a disturbance event from a water intake is considered the most important factor determining the likelihood of an impact on a water intake. However, the distance a given contaminant can travel is dependent on settling time and current velocities. For example, South Kalamalka Lake has stronger currents than North Kalamalka Lake based on data, which means the likelihood of a contaminant travelling a further distance is higher in the southern end of Kalamalka Lake during normal wind events. Also, sediments in Wood Lake have shorter settling times than sediments in Kalamalka Lake due to grain size. The shorter sediment settling times means that contaminants in Wood Lake cannot travel as far before they gradually settle back to the bottom, although liberated contaminants can remain suspended for longer. All licensed water intakes were considered on Wood and Kalamalka Lake. However, the domestic water intakes at the North and South ends of Kalamalka Lake were given a stronger influence on the likelihood index. For these two intakes, distances close to the previously determined Intake Protection Zones (IPZ) were used to quantify the likelihood of a contaminant reaching the water intake.

Table 7: Criteria Used to Determine Distance to Source Water Likelihood			
Likelihood Level	**North Intake (m)**	**South Intake (m)**	**Licensed Water Intake (m)**
A	Distance <350	Distance <500	Distance < 100
B	Distance >=350 & Distance<1000	Distance >=500 & Distance <1000	Distance >=100 & Distance <200
C	Distance >1000 & Distance <Average Distance	Distance >1000 & Distance <Average Distance	Distance >200 & Distance <Average Distance
D	Distance >=Average Distance & Distance <Maximum Distance	Distance >=Average Distance & Distance <Maximum Distance	Distance >=Average Distance & Distance <Maximum Distance
E	Distance >=Maximum Distance	Distance >=Maximum Distance	Distance >=Maximum Distance

The final index for source water protection likelihood model was calculated by combining the substrate, distance to source water, and depth indices (see Appendix A) with recreational activity index (Tables 6 and 8).

Table 8: Determination of Source Water Protection Likelihood Model						
	Depth, Distance to Source Water, Substrate Likelihood					
	Likelihood Level	**A**	**B**	**C**	**D**	**E**
Recreational Activity Likelihood	**A**	A	B	C	D	E
	B	A	B	C	D	E
	C	B	C	C	D	E
	D	C	C	D	D	E
	E	C	C	D	D	E

2.6.2 Environmental Risk Likelihood Model

The likelihood of recreational activity causing an event that impacts high value habitat was also quantified. The environmental value of areas within Kalamalka and Wood Lake is a function of proximity to high value habitat for fish, red/blue listed plants, and waterfowl. These areas included riparian wetlands, emergent/floating vegetation, and areas with a high or very high Aquatic Habitat Index (AHI) Rating. The likelihood index assumed that recreational activity needs to be in proximity to exert a negative environmental effect. For example, for an event to be possible (31-70%) the disturbance from a recreational event needed to occur within 250 meters of the high value habitat. The criteria used to determine areas of high value habitat is listed in Table 9. The environmental value index was combined with the likelihood of a recreational activity to calculate the likelihood of recreational activity causing an event that impacts high value habitat (Table 10). It is acknowledged here that environmental risk is challenging to quantify because it is species dependent. This means that each different species, and the habitats they utilize are affected in different ways. Since these species dependent relationships are complicated, reasonable assumptions were used to determine appropriate distances that considered a broad suite of species from fish to waterfowl.

Table 9: Criteria Used to Determine Recreational Activity Likelihood

Likelihood Level	Distance to High Use Beach (m)	Distance to Low Use Beach (m)	Distance to Beach Access (m)	Distance to Marina (m)	Distance to Boat Launch (m)	Boat Density (boats)
A	Distance <25			Distance <100	Distance <101	Boats >3
B	Distance >=25 & Distance <300	Distance <25	Distance <25	Distance >=100 & Distance <500	Distance >=100 & Distance <500	Boats <=3 & boats >2
C	Distance >= 500 & Distance <1000	Distance >=25 & Distance<500	Distance >=25 & Distance <500	Distance >=500 & Distance <1000	Distance >=500 & Distance <1000	Boats <=2 & boats >1
D	Distance >=1000 & Distance <2000	Distance >=500 & Distance <1000	Distance >=500 & Distance <1000	Distance >=1000 & Distance <2000	Distance >=1000 & Distance <2000	Boats <=1 & boats >0
E	Distance >=2000	Distance >=1000	Distance >=1000	Distance >=2000	Distance >=2000	Boats =0

Table 10: Determination of Environmental Risk Likelihood Model

		High Habitat Value Likelihood				
	Likelihood Level	**A**	**B**	**C**	**D**	**E**
Recreational Activity Likelihood	**A**	A	B	C	D	E
	B	A	B	C	D	E
	C	B	C	C	D	E
	D	C	C	D	D	E
	E	C	C	D	D	E

2.7 Software Used

The boat density and likelihood models used a combination of R version 3.13 (R Core Team 2015) and ArcGIS Desktop version 10.4.1 with Spatial Analyst (Environmental S ystems Research Institute 2016). The R packages sp (Pebesma and Bivand 2005), rgeo s version 03-11 (Bivand and Rundel 2015), rgdal version 1.1-3 (Bivand *et al.* 2015), an d raster version 2.5-2 (Hijmans 2015).

2.8 Risk Determination

To assess the overall risks associated with powerboat recreation on Kalamalka and Wood Lakes and to provide practical recommendations to minimize this risk, recommended travel corridors and recreating areas were determined. The environmental risk likelihood model was combined with the source water protection likelihood model to identify areas of low risk. The greater of the two likelihoods was combined to provide a conservative estimate of risk. The area that is approximately 100 m from the shoreline was deemed as a higher risk area and hence was not included as a recommended recreating areas. Areas that were considered moderate to high risk but for practical reasons need to allow boat travel were designated as travel corridors.

2.9 Project Assumptions

Throughout this project, we consistently chose the median or low end of estimates of impact to arrive at conservative, easily defensible estimates of risk. For example, we chose:

1) A 3 m depth as a point where sediment could be mobilized from prop wash, over the 5 m depth that would be more typical of fine marl substrates that are very common in Kalamalka Lake.

Water currents and their directions of travel were calculated using moderate winds, not strong winds or storms when water currents are stronger and faster (but when powerboating is less common).

Sediment hydrocarbon samples were taken months after the boating season had concluded, rather than during the peak use period, to allow conservative estimation of potential contaminants from recreational (or other) uses and activities

The models developed here included conservative parameters. For example, it was assumed that active powerboating recreation did not occur within 60 m of shore

At no time was the worst-case scenario(s) quantified for recreational impacts on Kalamalka and Wood Lakes. It is evident and assumed that a large event on these lakes, such as a wind storm with contaminated sediments in the area or a spill would affect the entire end of the lake involved. For example, an Intake Protection Zone that included the area water currents can travel in wind storm events within two hours would include the entire southern end of Kalamalka Lake. Similarly, the distance water currents can transport a contaminant to the North intake within two hours would include the entire North Arm. Since these scenarios are less likely, and a good understanding of the spatial risks are known, our focus was placed on typical activities and events to understand what the potential risks of normal use may be.

3.0 RESULTS AND DISCUSSION

3.2 Water Depths and Bathymetry

Bathymetry data was collected and can be found in the mapsets. Bathymetry data is best viewed graphically. As expected, shallow areas were predominantly located on the north and south ends of Kalamalka Lake.

3.3 Sediment Results

Sediment results from Kalamalka and Wood lakes showed several important natural features. The annual marl deposition in Kalamalka Lake produced sediments with very high calcium concentrations (Table 11). Marl substrates have a finer grain size than clay and have very slow settling rates. Wood Lake sediments had much larger nutrient concentrations than Kalamalka sediment samples. The release of sediment nutrients can cause conditions favoring growth of harmful algae bloom species such as cyanobacteria, and can also impact native mussels and benthic invertebrate communities that are considered important fish food. These findings are consistent with other studies (Larratt 2001; Larratt and Self, 2015; Walker et al., 1993).

Over the past 50 years both lakes have been influenced by activities that have contributed to sediment metal concentrations which exceed BC sediment quality guidelines (Tables 12 & 13). Metal contaminants that are not attributable to boating-related activities include arsenic, cadmium, chromium, copper, iron and nickel. Interestingly, these sediment metal exceedances only occurred in the north arm sediments of Kalamalka Lake and not in the south. The likely source of these exceedances are Coldstream Creek agriculture and urbanized storm water. The release of these contaminants by powerboat turbulence and subsequent sediment re-suspension is possible.

Sediment parameters that are indicative of direct powerboat impacts included a few metals and hydrocarbons. The sediment metal concentrations that exceeded guidelines in marina samples only, and not in adjacent lake sediment samples were selenium and zinc. These metals were found at marinas at the north end of Kalamalka and the south end of Wood Lakes respectively. Selenium can be released with greywater and its toxicity is increased when sediments are disturbed and the selenium remobilized. Zinc contamination arises from water in contact with galvanized metals and mobilized by turbulence from boat wakes.

Polyaromatic hydrocarbons and fuel additives (e.g., methyl tert butyl ether or MTBE) have been detected in lake waters and are a concern in drinking water, even at low concentrations (Asplund, 2000). Oil and gas leaks can occur from boat engines and are more likely if the engines are poorly maintained. Heavier oils persist in the water and can gradually build up in sediments. Contaminated sediment re-suspension is of particular concern due to the large shallow littoral zones of Kalamalka and Wood lakes. Spills are the leading cause of hydrocarbon contamination of lake sediments (BC WQG). Hydrocarbons were detected in the Oyama Canal and at two other large marinas. A variety of hydrocarbons were detected in the Oyama Canal, including EPHs19-32, HEPHs, chrysene, fluoranthene, phenanthrene, and pyrene (Table 12). Sediments from the marina on the south end of Kalamalka Lake contained the greatest concentration of hydrocarbons, which included EPHs19-32, HEPHs, fluoranthene and pyrene. Sediments from the marina at the south end of Wood Lake showed moderate concentrations of EPHs19-32, HEPHs and pyrene. Fine sediments can accumulate at marinas through disruption of longshore currents. The fine texture of the sediment at the canal and marina locations may have influence retention of hydrocarbons. Hydrocarbons were not detected at the Kalamalka Lake boat launch, possibly because of the sandy sediments and their associated texture resulted in faster rates of evaporation. Alternatively, this location may have had fewer inputs of hydrocarbon.

Hydrocarbons that exceeded Canadian Council of Ministers of the Environment (CCME) guidelines included pyrene at all three sites, fluoranthene at Oyama Canal and south Kalamalka Lake marina, and phenanthrene in the Oyama Canal. Oyama Canal had the most exceedances. The hydrocarbon samples were taken months after the boating season had concluded. Since evaporation of hydrocarbons does occur, the estimates and exceedances observed in these samples are conservative given that some quantity had likely evaporated or evolved since the peak boating season. Sampling in the mid-summer during the active boating season may result in higher concentrations and represent more worst-case conditions than what has been modelled here. Smaller marinas, and possibly even some residences, or other shoreline areas may also have hydrocarbon contamination but likely at lower concentrations than those detected at the largest marinas that have the highest use. Similar results are common observed in the Okanagan Mainstem lakes (Osoyoos Lake Water Quality Society 2016; Macdonald et al. N.D.). Shallow private intakes are much more vulnerable to hydrocarbon contamination from motorized recreation than the municipal intakes. This contamination is particularly risky because adjacent re-fueling near these shallow water withdrawals limits dilution of introduced hydrocarbon contaminants . *No water treatment exists that could protect against the range of potential contaminants found in Kalamalka Lake sediments.*

Table 11: Selected Nutrients and Hydrocarbons in Kalamalka and Wood Lake Sediments (mg/kg) – 2016									
Selected Analytes	**Kal N Shallow**	**Kal N Deep**	**Kal S Shallow**	**Kal S Deep**	**Oyama Canal**	**Kal S Marina**	**Kal N Boat Launch**	**Wood Lk Marina**	**N Wood Lake**
Date (d/m/y)	07/10/16	07/10/16	07/10/16	07/10/16	26/10/16	26/10/16	26/10/16	05/12/16	05/12/16
Nutrients									
Calcium	110000	100000	360000	350000	22000	180000	4800	45000	44500
Phosphorus	770	900	180	350	380	780	520	1300	1700
Potassium	1900	3000	430	1000	590	1200	510	1600	2530
Sodium	270	410	250	280	150	300	150	470	493
Sulfur	2900	4800	4200	4800	2300	8700	<1000	5800	12000
Hydrocarbons									
EPHs10-19					<64	<200	<50	<130	
EPHs19-32					250	890	<50	670	
LEPHs					<64	<200	<50	<130	
HEPHs					250	890	<50	670	
Chrysene					0.05	<0.1	<0.05	<0.1	
Fluoranthene					0.18	0.16	<0.05	<0.1	
Phenanthrene					0.11	<0.1	<0.05	<0.1	
Pyrene					0.15	0.17	<0.05	0.13	

Table 12: Sediment Hydrocarbon Exceedances Eckmann Samples (mg/kg dry) – 2016			
Parameter	**Value**	**CCME ISQG**	**Location Name**
Fluoranthene	0.18	0.111	Oyama Canal
Fluoranthene	0.16	0.111	Kal South Marina
Phenanthrene	0.11	0.0419	Oyama Canal
Pyrene	0.15	0.053	Oyama Channel
Pyrene	0.17	0.053	Kal South Marina
Pyrene	0.13	0.053	Wood S Marina

Table 13: Sediment Metal Exceedances Eckmann Samples (mg/kg dry) – 2016					
Parameter	**Value**	**BC Guideline**	**BC Average**	**BC SD**	**Location Name**
Arsenic	6.1	5.9	28.62	21.82	Kal N Deep 23m
Cadmium	0.6	0.6	1.45	1.88	Kal N Deep 23m
Chromium	41	37	233.5	259.8	Kal N Deep 23m
Copper	41	36	677.9	1496	Kal N Deep 23m
Iron	29000	21200	205100	201900	Kal N Deep 23m
Nickel	17	16	20.24	16.11	Kal N Shallow 14m
Nickel	27	16	20.24	16.11	Kal N Deep 23m
Selenium	5.1	5	13.97	6.03	Kal S Marina 1m
Cadmium	0.65	0.6	1.45	1.88	Wood S Marina 1.5m
Chromium	38.6	37	233.5	259.8	Wood N 14m
Iron	29000	21200	205100	201900	Wood S Marina 1.5m
Iron	32100	21200	205100	201900	Wood N 14m
Nickel	22	16	20.24	16.11	Wood S Marina 1.5m
Nickel	32.9	16	20.24	16.11	Wood N 14m
Zinc	190	123	112.9	146.8	Wood S Marina 1.5m

Table 14: Sediment Trap Data (g) – Summer 2016						
Site	**Depth (m)**	**Dry Wt.**	**Organic**	**Inorganic**	**% Organic**	**Accum. (g/day)**
Kal S Shallow	3	2.35	0.477	1.873	25	0.034
Kal S Shallow	3	2.82	0.529	2.291	23	0.040
Kal S Deep	24	2.04	0.242	1.798	13	0.029
Kal S Deep	24	2.1	0.414	1.686	25	0.030
Kal N Shallow	14	1.85	0.19	1.66	11	0.026
Kal N Shallow	14	2.19	0.224	1.966	11	0.031
Kal N Deep	23	1.82	0.333	1.487	22	0.026
Kal N Deep	23	0.826	0.114	0.712	16	0.012

Table 15: Sediment Fall Tests – 2016				
Bacterial sed. jar upper 5 cm sediment (21°C)	Kal S Shallow	Kal S Deep	Kal N Shallow	Kal N Deep
time to clear water (h)	1	11	80	72
fully settled	48	96	>145	145
Bulk Eckman dredge samples (10°C)	Kal S Shallow	Kal S Deep	Kal N Shallow	Kal N Deep
time to clear water (h)	1.5	4	3	15
fully settled	14	54	24	68
Bulk Eckman dredge samples (21°C)	Kal S Shallow	Kal S Deep	Kal N Shallow	Kal N Deep
time to clear water (h)	1.2	6	2.5	22
fully settled	13	85	26	>85
Bulk Eckman dredge samples (21°C)	Wood N	Wood N	Wood S Marina	Wood S Marina
time to clear water (h)	0.65	0.7	1.6	1.6
fully settled	6	6	8	8
Bulk Eckman dredge samples re-stirred (21°C)	Wood N	Wood N	Wood S Marina	Wood S Marina
time to clear water (h)	0.6	0.6	0.8	0.9
fully settled	3.5	3.5	4.3	4.5

3.3.1 Sediment Trap Results

The Kalamalka Lake sediment traps collected sediments falling to the substrates during the peak boating period. Sediment accumulation rates in north Kalamalka Lake were 1.65 $g/m^2/day$ and 1.08 $g/m^2/day$ for shallow and deep traps, respectively. Sediment accumulation rates in south Kalamalka Lake were greater at 2.11 $g/m^2/day$ and 1.69 $g/m^2/day$ for shallow and deep traps, respectively (Table 14).

Shallow sediment traps collected more material than their deep counterparts at both ends of the lake, indicating greater sediment resuspension from a combination of boat wakes and waves, as well as sediment introduction from on-shore sources. Additionally, seiche-driven sediment re-suspension decreases linearly with depth, meaning that as depth increases the rate of sediment deposition decreases (Hilton et al., 1986; Howard, 1971),

Sediment deposition rates were greater at the shallow and deep sites in south Kalamalka when compared to the north end, despite the influence of Coldstream Creek as a sediment source in the north. Overall, the south traps had more organic material (algae, etc.) than the north traps. Waves erode the shallows and mixing transfers sediment to deeper water. This all suggests that the south end of Kalamalka Lake is sensitive to substrate disruption and mobilization.

If these results are extrapolated to an entire year of deposition, and assuming deposition does not vary over the course of a year, sediment accumulation would range from 394 g/m^2/yr at the north end of Kalamalka Lake to 770 g/m^2/yr at the south end in the shallows of the lake. These sediment accumulation rates were higher than those calculated in other studies of Kalamalka Lake (Larratt 2011), and those calculated for European marl lakes (300 - 400 g/m^2/yr)(Rose et al., 2011; Wilk et al., 2015). The rates calculated here for Kalamalka Lake are possibly higher than those elsewhere because summer powerboating increases sedimentation rates through re-suspension. While other sources cannot be ruled out, the air photo evidence, combined with the understanding of boat wake / propeller turbulence all suggest that it is a potential contributing factor. Regardless of source, these data indicate that the shallow marl sediments of Kalamalka Lake are vulnerable to sediment resuspension, particularly at the south end of the lake.

Sediments, once mobilized are more likely to reach deeper water when lakebed slopes are greater than 4% (Fassbender et al., 1992; Hakanson 1977). In shallow areas of Kalamalka Lake, it is probable that sediment is mobilized to some extent. Since the slopes with a depth from 2 m to 23 m is 5%, and sediments will not reside on underwater slopes steeper than 14%, it is possible that mobilized sediments may begin downward migration towards the intake. This means that some of the sediment detected in the deep sediment traps would have originated from the shallows and is not entirely the result of whole-lake phenomena such as marl precipitation and settling of algae cells. This all suggests that our assumptions for the spatial model are conservative.

3.3.2 Sediment Fall Tests:

Fall velocity is an aggregate measure, which includes sediment grain size, shape, and density, and it helps quantify the susceptibility of lakebed sediment to resuspension (Beachler and Hill, 2003). A series of fall tests were undertaken and these fall tests provided important observations (Table 15).

For Kalamalka Lake sediments, aggregate clumps of sediment settled to the bottom of the flask in minutes, but the time to achieve clear water and fully settled conditions were lengthy. After sediments settled for 3-5 hours, they re-suspended more readily than sediments that were un-disturbed for a week. Apparently the settled sediments became more consolidated or had more bacterial activity increasing their cohesion. All shallow sediments had more visible organic content than deep sediments including macrophyte fragments, with the macroalgae *Chara* observed in samples from the south end of Kalamalka Lake. In a trial using surface sediments only, those from shallow areas left a haze in the water column for over one week, indicating that fine particulates (marl, bacteria) could remain suspended indefinitely in still water.

There were differences between the Kalamalka Lake sediments collected from the north and south ends, irrespective of collection depth. South sediments were lighter and had more decaying organic matter, with far more marl content that was the slowest to settle. These very fine marl sediments would be the last to settle and would remain on the top of lake bed sediments. Despite their marl content, south Kalamalka Lake sediments settled faster than samples from the north end, likely due to their organic content. North Kalamalka Lake sediments were darker and sandier than south sediments, and they also had a very fine silt fraction that was very slow to settle. Deep north Kalamalka sediments settled leaving a slight haze for over one week. While the Coldstream freshet imported larger particles, the particles sampled in the north arm water column were < 70 microns during 2003, <75 microns during 2004, and <57 microns in the 2005 samples (Larratt, 2005). Overall, sediments collected from the north end of Kalamalka Lake took much longer to settle than sediments collected from the south end of Kalamalka Lake. We suspect that this is due to the greater organic content of south sediments that would encourage particulates to aggregate into larger particles.

In contrast to the slow fall rates observed for Kalamalka Lake sediments, Wood Lake settled much more rapidly (Table 15). The sediment from the north end of Wood Lake collected at a depth of 17 m consisted of dark grey silt, while sediments from the south Wood Lake marina were a black anaerobic gel. The marl component of Wood Lake sediments is much smaller than that of Kalamalka Lake sediments, but the organic content is generally greater. The fall rates measured were slower for the gel substrate found in the Wood south marina than they were for the deeper Wood north substrates.

These fall rates indicate how long suspended sediment (turbidity) can be expected to persist in completely calm water, and were used to conservatively estimate impacts on drinking water intakes. Actual time that sediment can remain suspended will be longer in these lakes because there is always movement in the water column.

3.3.3 Bacteria Fall Tests:

Bacterial tests were completed using the bulk samples, which were composites of the upper 15 cm of sediments. Although 99% of the bacteria in a lake system live in the upper few centimeters of substrate, these samples would represent a conservative estimate of bacterial densities since most of the sample volume was from older, deeper, substrate with lower bacterial counts.

The fall velocity of fine clay is small, about 1 m/day, for marl it is about 0.6 m/day and for *E. coli* bacteria it is far smaller at 0.00354 m/day (Hayco, 2009; USGS 2007). It will take several weeks for clay to settle through the water column; less if it clumps with other materials (larger sediment particles, organics). Marl particulates are in the same size-range as bacteria but they readily clump with bacteria and other organics, and settle out of the water column gradually over a period of months. It could take years for bacteria to settle out based strictly on individual cell fall velocity. Their fall velocity will be accelerated by clumping with other suspended materials. Bacteria can also be consumed by zooplankton and deactivated by sunlight or aging (Wetzel, 2007).

In the Kalamalka sediment bacteria fall tests, water column bacterial samples were collected after one hour, when most of the visible sediment had cleared and after three days when all cloudiness in the water had settled. As with all sediment tests conducted over the past three decades, the north arm, deep sediments contained *E. coli* (likely from Coldstream Creek) while sediment from the deep areas in south end did not

(Table 17). The shallow sediments at both ends of the lake have shown positive *E. coli* results and these can be from stormwater, waterfowl, pets, etc. Pathogens can survive in sediments for months, in contrast to a faster die-off in the water column (Burton et al., 1987). There are numerous potential health risks from microbial contamination, mostly in the form of enteric disease.

All types of bacteria took longer to settle in our samples than the sediment particles fall tests (Table 17). Interestingly, some bacteria were still detected in the water column after three days in north Kalamalka Lake sediment fall tests in a completely still water column. Together these results confirm research elsewhere in which sediment disturbance can release pathogens that, under the right conditions can migrate to water intakes because these contaminants can exist in the water column for several days (Burton et al., 1987; Christensen and Linden 2003). These results also confirm that the risk is greatest within days of the disturbance and diminishes after that.

Table 16: Typical sediment fall rates

Material	Size	Fall velocity
Inorganic		
Sand	>63 – 300 microns	> 100 m/day (15 cm/s)
Silt	4 – 63 microns	21 m/day (1-2 mm/s)
Clay	0.1 – 4 microns	1 m/day
Marl	<1.5 microns*	0.6 - <0.03 m/day
Biological		
Organic clumps	> 100 microns	< 100 m/day
Organic clumps (detritus)	< 100 microns	0.35 m/day
Large algae and diatoms	22 – 70 microns	< 50 m/day
Small algae	6 – 14 microns	<1 m/day
Lrg filament cyanobacteria	5w x 200l microns	0.1 m/day
Sm filament cyanobacteria	1w x 100l microns	>0.007 m/day
Giardia / crypto cysts	4 – 8 microns	0.02 - 0.1 m/day
Bacteria – *E. coli*	0.7 – 10 microns	>0.0035 m/day

(Dia and Boll, 2006; USGS 2003; USGS 2007; Hayco, 2009; Larratt 2010, Beachler and Hill, 2003)
* Particle size determination for Kalamalka Lake water showed marl size averaged 1.1 microns (Larratt, 2005)

Table 17: Bacteria in Kalamalka Lake sediment samples.

	Kal N Shallow	Kal N Deep	Kal S Shallow	Kal S Deep	Kal N Shallow	Kal N Deep	Kal S Shallow	Kal S Deep
Analyte	One hour after disturbance				Three days after disturbance			
Coliforms, Total	>= 17	>= 17	<10	Overgrown with	<3	3.6	<3	<3
Background Colonies	> 200	> 200	> 200					
E. coli	8	<1.2	>= <1.3	<1.3	<3	<3	<3	<3

3.4 Municipal intake data

The District of Lake County (DLC) collects turbidity, temperature and bacterial data weekly or twice weekly from their south Kalamalka intake. Their data shows the typical summer increase in turbidity, attributable to the 2016 marl deposition (Figure 3). During 2016, there were 4 dates when turbidity was elevated over 1.5 NTU. One of these events was attributable to a seiche. The other two events, however, were not likely the result of this wind mechanism. All three events had associated bacteria counts. While it cannot be confirmed, this data, combined with the physical characteristics of these lakes all suggest that sediments can be mobilized and reach the point of intake, and that powerboat recreation may to some extent be mobilizing sediments. Boat traffic has been correlated with up to a 50% increases in turbidity in many studies (e.g., Anthony and Downing 2003; Beachler and Hill 2003).

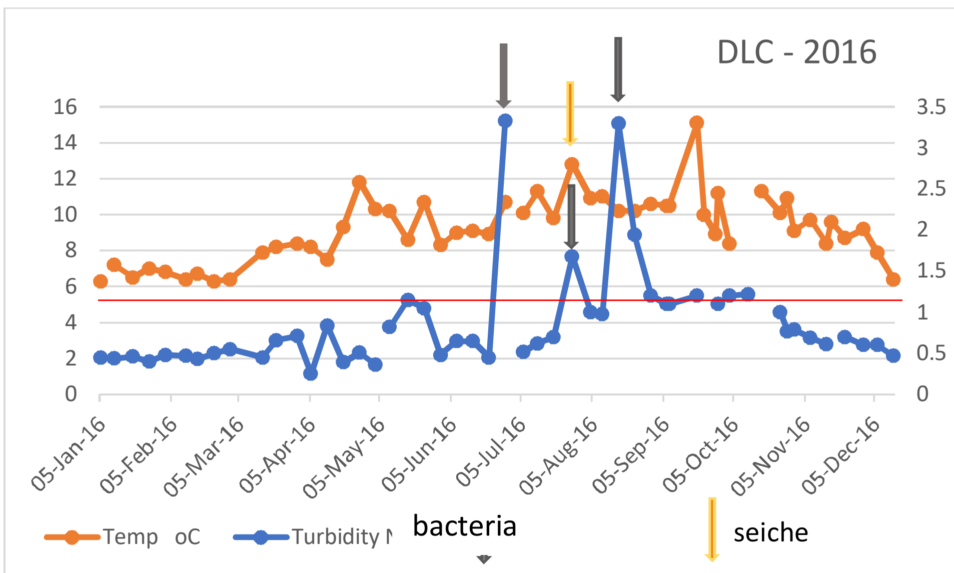


Figure 3: Temperature and turbidity data from District of Lake Country, 2016.

3.5 Lake Current and Water Movement

3.5.1 Seiche Effects

Seiches and water currents direct the movement of "water parcels" or discrete inflows that gather in localized areas and travel as a mass while their edges gradually mix with an increasing volume within the lake. They are the delivery system for surface contaminants to deep intakes; shallow intakes are already within the surface water layer and are far more vulnerable to surface water contamination. For example, Coldstream Creek plumes often travel as a "river of water" within Kalamalka Lake. Similarly, silt plumes that could develop from large power boats accelerating rapidly in the 1-3 m deep shallows would gradually disperse and dilute with the distance travelled. Seiches increase the vulnerability of an intake to contaminants introduced to the surface water layer by powerboat turbulence, a storm water outfall or a spill for example.

The main transport mechanism of surface contaminants to the Kalamalka Lake intake is seiches in the May – October stratified period. Seiches are wind-driven standing waves within a waterbody. North or south-west winds with gusts exceeding 30 km/hr could generate a seiche depending on the duration of the wind event. The shallows and the marinas would all be within the epilimnion or upper water layer of the lake during the peak summer recreational period (June through September) in both lakes. The thermocline separating the surface water layer from the underlying hypolimnion would provide a barrier, protecting the intake from sediment disturbance in the shallows under calm conditions.

Turbulence and seiches are more intense at the south end of Kalamalka Lake than they are at the north due to the shape of the lake basin. Seiches produce noticeable spikes in water temperature, conductivity, turbidity, color and algae densities at the existing 22m Lake Country intake an average of 20 times in the summer (Larratt, 2010). With the proposed 30 m intake completed, seiches reaching the intake depth would only occur about 8 times per summer (Larratt and Self, 2014). At the north end of Kalamalka Lake, a similar scenario is observed with water layers and currents, but in this area there is only 10 seiches reaching the existing 20 m intake. If this intake is extended to a 30m depth, approximately 4 seiches will reach the intake each summer. In the north end of the lake, the correlation between seiches and turbidity events is well established using a continuous SCADA dataset.

3.5.2 Water Current Travel

As part of this study, drogues were used to measure water currents under variable, moderate winds in South Kalamalka Lake on five occasions in 2015 (depths = 0.5 m and 1 m) and on three occasions in 2016 (depths = 5m 10m 20m and 30m). Drogues were deployed on three 2016 dates near the north Okanagan intake in 2016 (depths = 5 m, 10 m, 20 m, and 30 m). The effect of wind on currents decreases with depth. Shallow water responds faster and with greater water current velocities than deeper water. For example, drogues averaged 91 m/hr at the surface and 71 m/hr at 1 m below the surface, but only 41 m/hr at 5m depth and 26 m/hr at 30 m depth in the southern parts of Kalamalka Lake. In the North Arm under gentle winds, the 5m drogue averaged 57m/hr, the 10m averaged a similar 60 m/hr and the 20 m was slower at 34 m/hr.

Kalamalka Lake water currents generally move parallel to the wind with a few notable exceptions. At the South end, south winds blew from either the southeast or southwest which led to the formation of longshore currents along the windward shore. Drogues in open water were drawn towards the shore and into the longshore currents. Similarly, at the north end there was one occasion when the 5m drogue responded quickly to a north wind, while the 20 and 30m drogues continued travelling west, due to an earlier northwest wind.

At the south end of Kalamalka Lake, wind from the north generated currents that did not pose a risk of transporting contaminants to the drinking water intake while a southwest wind would push any contaminants from the busy Oyama Canal / marina area towards the eastern shore and then on a trajectory towards the DLC intake. At the current speeds recorded, a contaminant spill at the marina / canal would take about 8 hours to reach the DLC intake from this heavy-use area. In shallows adjacent to the south intake, a sediment plume from powerboating or other disturbance could form within 150 m of the DLC intake and would take less than 2 hours to reach the intake.

At the north end of Kalamalka Lake, similar rules governing water layers and currents apply so that 10 seiches reach 20 m and 4 reach 30 m depths. Here the correlation between seiches and turbidity events is well established using SCADA monitoring. Using the 2016 drogue speeds, travel times of boat-induced sediment plumes from adjacent shallows to the north Kalamalka intake would be under 2 hours and as fast as 30 minutes under moderate winds. A spill at the Kalavista boat launch could reach the intake in 3 – 5 hours, depending on the depth of travel and under moderate winds. During storm events, the impacts of spills or contaminated sediments would reach the intake sooner, so that impacts could be felt at the intake from most of the North Arm in under 2 hours.

3.6 Summary of Sediment Re-suspension on Intake Turbidity

The results of sampling and testing sediments in this project confirm earlier work from these lakes, as well as confirming general lake research on boating impacts on sediment resuspension. The impacts of sediment resuspension on turbidity measured at municipal intakes involves the transport of deposited contaminants including bacteria, heavy metals, and hydrocarbons at refueling facilities (Larratt, 2001; Walker et al. 1993), The small particle size of the marl substrates is especially concerning because they are so easily mobilized. Bacteria and viruses occur at the highest concentrations in the upper few mm of sediment, which is the layer most susceptible to resuspension by turbulence Mobilized substrates can have a direct effect on an intake either through uptake of contaminants or by reducing the effectiveness of treatment through increased turbidity.

Sediment plumes of contaminants can travel from disturbed areas to intakes following prevailing water currents into deeper water. Risks to water quality are based upon numerous factors including the location of activities, boat densities and type, substrate type, contaminant loads of those substrates, and water depth. Another factor that warrants consideration include erosion resulting from large wakes, which poses both a significant environmental risk and a potential source water risk through sediment plumes.

Shallow private intakes are at greater risk from most types of contamination than deeper municipal intakes (>20m), because they occur in the surface water layer, have less dilution available from the point of contamination to the intake, and they generally have minimal treatment.

3.7 Boat Density and Carrying Capacity

When all information was cumulated into the spatial density model, and calibrated using actual boat count data from 2016, the results indicated that densities were greatest in several key areas. Boat utilization was categorized into four categories within a given area:

1) Low density was treated as having less than 1 boat per cell;
2) Moderate density was treated as having 1 boat per cell;
3) High density was 1 to 3 boats per cell; and,
4) Very High density was treated as greater than 3 boats per cell.

While the number of boats per 500 m X 500 m grid cell may seem low, the area was chosen because it represents an approximation of the area needed for active recreation, where some boats are active and some are at idle (Table 18), given that the literature provides a very wide range of values in the area that boats need to safely recreate. The value of 20 acres per boat was chosen as a reasonable estimate. Our 250,000 m^2 cell is approximately 61 acres, meaning that 3 boats would be a high density and 4 would potentially exceed this (at 4 boats, the density is 15 acres/boat).

Boat densities were generally moderate or high throughout most areas of Kalamalka Lake (Mapsheet 1-4, Boat Density Figure Binder), meaning that there were 1 to 3 boats in the 250,000 m^2 or 60 acre grid. This resulted in a few places that may have had densities that were high enough to exceed capacity in several locations on Kalamalka Lake (Mapsheet 1-4, Modelled Carrying Capacity). In general, exceedances were observed in areas of very high utilization in north east of Owls Nest, eastward of Crystal Waters, proximal to a private property reserve on the east side of Kalamalka Lake in the south end, in an area commonly used for cliff diving adjacent to Kalamalka Lake Provincial Park, and in the south end of the lake. On Wood Lake, nearly the entire lake was found to have a low and moderate densities. There was one area near the Oyama Channel that had high boat density, however, it did not exceed the carrying capacity.

These results highlight that some areas of the lake often exceed densities (more than 20 acres per boat) that are deemed safe for powerboating. We acknowledge that the model uses limited data; the actual densities may vary from the predicted values in either density, and location to some extent. However, the boat count data used to calibrate this model confirm that these densities are commonly observed. A significant challenge with developing a model such as this relates to the ratio of powerboats actively recreating versus those that are passively floating. Insufficient data was available to develop a full model considering the relative ratio of active versus passive powerboat recreation. Despite these shortcomings, an attempt was made to determine areas where recreational carrying capacity may be exceeded. This was accomplished by assuming that all boats within a given cell were recreating and that 20 acres per boat was needed to safely recreate. Using these assumptions, cells that exceeded this amount were considered at or exceeding the potential capacity of the area. Like the boat density model, this analysis confirmed that many areas of the lake are currently at or exceeding the carrying capacity. If the area per powerboat needed to safely recreate is decreased to 15 acres per boat for example, then more of the lake would be under the carrying capacity, however if the area is increased to 30 acres per boat, then more of the lake would be exceeding capacity. The following table provides a summary of different papers, highlighting that the use of 20 acres per boat is a reasonable area to use for the purposes of determining carrying capacity (Dearlove and Molinaro, 2004).

Table 18: Summary of available information on boat recreation density, taken from Dearlove and Molinaro, 2004.

Source	Boating Uses	Suggested Density
Ashton (1971)	All uses combined in Cass Lake	5 to 9 acres/boat
	All uses combined in Orchard Lake	4 to 9 acres/boat
	All uses combined in Union Lake	6 to 11 acres/boat
Kusler (1972)	Waterskiing combined with all other uses	40 acres/boat
	Waterskiing only	20 acres/boat
	Coordinated waterskiing	15 acres/boat
Jaakson et al. (1989)	Waterskiing and motorboat cruising	20 acres/boat
	Fishing	10 acres/boat
	Canoeing, kayaking, sailing	8 acres/boat
	All uses combined	10 acres/boat
Wagner (1991)	All boating activities	25 acres/boat
Warbach et al. (1994)	All motorized (>5 HP) uses	30 acres/boat

Table 2: Optimal Boating Densities and Associated Carrying Capacities for Lake Ripley.

Lake-Use Mix	Optimum Boating Density (Acres/Boat)	Useable Lake Area (Acres)	Carrying Capacity Total # of Boats)
100% Idle Speed or Stationary	10	378	38
75% Idle Speed or Stationary & 25% Fast-Moving	15	260	17
50% Idle Speed or Stationary & 50% Fast-Moving	20	260	13
25% Idle Speed or Stationary & 75% Fast-Moving	25	260	10
100% Fast-Moving	30	260	9

3.8 Source Water Protection Likelihood Model

The results of the likelihood model suggest that the area's most vulnerable to recreational power boat use occur in shallow areas of the lakes. In particular, the north and south ends of Kalamalka Lake were identified as key zones where the likelihood of a contamination event was considered greatest. This result is driven by the following facts:

1) These areas tended to have the greatest areas of water less than 3 m depth.
2) These areas tended to have the finest littoral sediments.
3) These areas tended to have the greatest potential for sediment-borne contaminants; and,
4) These areas were in closest proximity to public water drinking intakes.

On Wood Lake, the effects of recreation were much less apparent. While this lake has a large littoral zone, this is likely the result of fewer water intakes. Areas of potentially high concern all coincided with areas of private water intakes, occurring in shallow water zones.

3.9 Environmental Risk Likelihood Model

Environmental risks associated with recreation are more challenging to determine. However, recreation does pose several potential risks, and the following summarizes species, or species assemblages and mechanisms which could be affected:

1) Avian nesting can be affected by boat wakes, where large waves have the potential to overturn or flood nests. Many avian species are known to nest on floating vegetation, which are highly susceptible to being overturned by wakes.

2) Avian nesting can also be affected by noise. Many species are known to nest proximal to shoreline areas. High noise levels, common to many larger vessels, could affect where birds nest or the success of nests once they are constructed.

3) Many species of fish spawn in shallow, shoreline areas with suitable substrates. On Kalamalka and Wood Lakes, shore-spawning kokanee are the species of greatest concern. On Kalamalka, Lake Trout also likely shoal spawn in some areas, given that there is a viable population in the lake. Finally, many coarse fish of the minnow or sucker families may also shore spawn. Since boats have the potential to liberate sediment, it is possible that increased sedimentation, caused by either boat wakes generated in deeper areas, or by shoreline erosion, could reduce the potential value of spawning areas.

4) Sediment disruption and subsequent settlement has the potential to affect or reduce the productivity of the benthos. The liberation of sediment affects primary productivity, including algal growth that is good forage for fish, or creates forage for benthic invertebrates and zooplankton that fish eat. While quantifying this is challenging, lake productivity is an extremely important factor for fisheries and the entire aquatic ecosystem.

5) Most native mussel species tend to live submerged in areas of fine sediments. The disruption of shallow, fine, lakebed sediments has the potential to harm mussel individuals. If habitats are regularly disrupted, there is the possibility of local extirpation.

6) Amphibians or their egg masses may be disturbed by wakes.

The spatial model built for this project included criteria to address each of these different risks in some fashion. Then, using appropriate buffers, risks were determined.

The resultant maps shows that environmental risks associated with powerboat recreation, once buffers were included, tended to occupy a greater physical area than the Intake Protection Zones (IPZ) around municipal water intakes. This occurred because species utilization around the lakes occupies a much larger area, when compared to the fixed water intakes. In general, areas in the north and south ends of Kalamalka Lake, and many areas of coarse, angular substrate (used for Kokanee spawning), all tended to have very high environmental risks associated with them. On Wood Lake, areas of very high environmental risks tended to occur in closer proximity to either shore spawning areas, or in areas with emergent vegetation that could potentially be used by avian species.

3.10 Overall Risk Determination

To determine the overall risks associated with powerboat recreation on Kalamalka and Wood lakes, the spatial outputs of the source water likelihood and the environmental risks were overlain, because they utilized the same cell or grid pattern. Once this was done, the greater of the two risks was then selected. The most appropriate boat commuting pathways were determined by using the combination of the source water protection and environmental risk likelihood model, while taking into account practicality.

4.0 RECOMMENDATIONS

The following recommendations are intended to address and help mitigate power boat recreational impacts on Wood and Kalamalka Lake. Implementation of these recommendations will occur within a variety of varying regulatory frameworks. Often, many of these will require collaboration between different levels of government. Since there is a multi-jurisdictional nature to the concerns, a collaborative approach between all levels of government is necessary to achieve the desired outcomes.

4.1 Spill Safe Guards

The following are specific recommendations to address spills at the marina and provide some safeguards:

1) SPILLS All hydrocarbon spills exceeding 10 L (2.6 gallons), which could form a sheen covering 3 hectares, and all solvent or sewage spills exceeding 1 L be reported to the District of Lake Country, District of Coldstream, or Regional District of North Okanagan immediately. The specific details of the reporting requirements, including when, to whom, and other pertinent details should be included in a detailed Spill Response Plan that is satisfactory to the District of Lake Country, District of Coldstream, and Regional District of North Okanagan to protect the Community Drinking Water source. A spill response plan should be prepared by all commercial enterprises that offer fueling facilities. A more general spill response plan should be prepared and issued to all private moorage licensee's through the Province at the time of tenure or licensing. While fueling at private moorages is strongly discouraged, it is extremely challenging to prevent these activities from occurring, which acts to increase the potential risks to water intakes, particularly

the private ones that are usually shallower than 10 m. It is noted here that these guidelines may differ from Provincial spill reporting requirements, and all reporting should conform to Provincial guidelines.

At no time should soap, or other emulsifiers be used to "make fuel disappear". This practice binds up the contaminants and reduces the potential for evaporation, while increasing their transport into the substrates. While the contaminant spill may appear to be addressed using soap, it increases the potential for intake contamination by increasing the hydrocarbon concentrations in the water column.

This could be addressed through local government in some fashion. Currently, we understand the Provincial requirement is 100 L, which is greater than what is recommended here. Collaboration is needed because notification allows water purveyors the opportunity to work with Interior Health to determine if a public announcement is needed. The specific quantities recommended in here can be adjusted based upon additional considerations of risk if needed.

2) SPILL KIT A petroleum spill kit should be readily available onsite, and ready for deployment at all commercial facilities. The kit should be sized to the largest anticipated spill, which should be determined in the Spill Response Plan. All users of the site should be trained in the appropriate use of the spill kit. This is likely easy for local government to implement in zoning bylaws.

3) FUELING All fueling should occur at a designated facility only. Signage should be posted prohibiting on-water fueling using small "jerry" cans or similar types of fueling. If users wish to fuel boats using such methods, the boats should be removed from the water, and fueled in a location that will not result in spills migrating to the lake via surface water runoff such as the boat parking areas. Fuels used in the marina fueling should be free of additives such as MTBE (added to reduce carbon monoxide emissions) because the additives pose a greater risk to drinking water than boat fuel. This can be easily implemented at the local government level.

4) BYLAWS Bylaws, either through a municipal or strata body, which include formal resolutions should be developed that prohibits water vessel cleaning, painting, and other activities involving solvents. This would also apply to any on land activities, where it is possible for effluent runoff to reach the lake (e.g., within the boat parking area, occurring on an adjacent property).

5) BOAT LAUNCHES All boat launch structures should be reviewed to determine the potential for sediment disruption, largely based upon vessel size. All launches that are not associated with a license or tenure should be actively sought out, and decommissioned. At the time of permitting, an appropriate vessel size should be determined, and posted at the launching facility. The intent of this is to ensure that launching vessels, especially in shallow, fine sediment, and higher risk areas, are designed to avoid sediment disruptions. On busy days, extensive sediment disruption could result in a sediment plume that could impact source water intakes. The boat launch located at the south end of Kalamalka Lake is of particular concern.

It occurs in a higher risk area of fine marl substrate, and is proximal to a municipal intake.

4.2 Propeller, Wake and Wave Safe Guards

The following are specific recommendations specific to all marinas, whether commercial or strata, to help mitigate the risks associated with turbulence from boat wake or propellers which can occur during commute to and from the marina:

1) NO-WAKE LITTORAL PROTECTION ZONE A no-wake zone or speed limit should be introduced. This should be appropriately signed within all shallow, high risk areas identified within this report. This is most important at the south and north ends of Kalamalka Lake, especially along the Oyama Canal, which is the primary commuting pathway between the Wood and Kalamalka lakes. This no-wake zone should be established matching the model output maps provided here (Figure 3), with a width of approximately 100m and covering waters less than 3 m deep. If access through this zone is necessary, a speed limit of 10 km/hr of a "No Wake Policy" should be posted and strictly enforced. For reference, Waterski & Wakeboard Canada strongly recommends that wakeboard boats stay a minimum of 50 meters from any shore and in a minimum of 2 meters of water to reduce the effect of shoreline degradation and turbidity. Other legislation cites 100 m and 200 m exclusion zones for boats operating under power. The Small Vessel Regulations of Ontario stipulate that the legal speed limit for all motor boats is 10 km/h within 30 meters of any shore. A voluntary speed limit introduced by the shipping industry in the Montreal area demonstrated that shoreline recession decreased by as much as 45% in certain areas within three years (Fisheries and Oceans Canada, n.d.).

   It may be desirable to encourage paddle craft to operate within the no-wake littoral protection zone as they represent a far lower risk than power craft and should reduce the risk of collisions, to the benefit of all.

   This recommendation would involve multiple different agencies to facilitate. On water signage is necessary to educate the public about high risk areas.

2) LOW-RISK TRAVEL ROUTE A preferred route of travel on the south end of Kalamalka Lake, from the Oyama Canal to deeper water zones should be designated and appropriately marked with buoys and signed to facilitate a low-risk commute through the shallow water area between the lakes. A framework for self-policing, where residents would understand and be able to identify vessels in non-compliance should be developed. The preferred route should be registered with Transport Canada and appropriately marked using official marking buoys. This would require application(s) with various agencies such as Transport Canada, and the Ministry of Forests, Lands, and Natural Resource Operations.

This recommendation would involve multiple different agencies to facilitate. On water signage is necessary to educate the public about high risk areas.

3) WATER QUALITY ALERTS Total suspended solids testing should occur to document the effectiveness of the "No Wake Policy" and determine if the speed limit is appropriate. If TSS samples show significant elevation above background turbidity (> 8 NTU is the aquatic guideline standard, noting that 1 NTU is a drinking water standard), the policy should be amended by reducing the speed limit.

   The District of Lake Country, the District of Coldstream, or the Regional District of the North Okanagan should be notified if turbid water plumes are observed. The specifics of the notification should be documented in the Spill Response plan or in another marina safety or operational policy plan. The requirements for notification should be developed in conjunction with DLC to their satisfaction to protect the community drinking water source. This notification will help the DLC better understand if, when, and how often events occur as a result of sediment disturbance in the shallow water areas of Kalamalka Lake.

4) WATER BALLAST All wake boats should empty their water ballasts prior to return to a marina for moorage or prior to travel through the canal between the lakes. This policy should be posted on buoys by the canal, and at all marinas on the lakes, and will help lower the risk of sediment disturbance and invasive species transport.

4.3 Educations

The following are specific recommendations to facilitate education, a key and necessary component to educate the recreating public:

1) EDUCATION An educational program for users of Kalamalka and Wood lakes should be prepared and include information on the importance of little to no wake along the sensitive shoreline areas or to the highly sensitive shallow water areas identified in this report. It is apparent that human behavior plays a key role. Well planned educational initiatives are needed to change our perception of what lake shorelines and their respective habitats or environmental services represent. Society needs to begin to treat these areas as having high economic value because of the services they provide. In doing so, there will be a greater acceptance and effort made to integrate ourselves into the natural environment, rather than adapt it to our preference.

REFERENCES

Ashton, P.G. 1971. Recreational boating carrying capacity: A preliminary study of three heavily used lakes in southeastern Michigan. Doctoral Thesis, Department of Resource Development, Michigan State University.

Asplund, T. R. 2000. The Effects of Motorized Watercraft on Aquatic Ecosystems. Wisconsin Department of Natural Resources, Bureau of Integrated Science Services and University of Wisconsin – Madison, Water Chemistry Program March 17, 2000 PUBL-SS-948-00

Anthony, J.L. and J.A. Downing. 2003. Physical and chemical impacts of wind and boat traffic on Clear Lake , Iowa , USA . Lake and Reservoir Management.

BC WQG BC Water Quality Guidelines http://www.env.gov.bc.ca/wat/wq/BCguidelines/pahs/pahs-03.htm

Beachler, M.M. and D.F. Hill, 2003. Stirring up Trouble? Resuspension of Bottom Sediments by Recreational Watercraft Lake and Reservoir Management 19(1):15-25, 2003

Burton, G. Allen, Douglas Gunnison and Guy R. Lanzai, 1987. Survival of Pathogenic Bacteria in Various Freshwater Sediments. APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Apr. 1987, p. 633-638

Christensen, Jason and Linden, Karl G., 2003 How particles affect UV light in the UV disinfection of unfiltered drinking water. American Water Works Association. Journal; Denver 95.4 (Apr 2003): 179

Dai, X., & Boll, J. (2006). Settling velocity of Cryptosporidium parvum and Giardia lamblia. *Water Research*, *40*(6), 1321–1325. doi:10.1016/j.watres.2006.01.027

Dearlove, Paul and John Molinaro, 2004. Lakeline Vol 24, No.2 Summer 2004. North American Lake Management Society.

Environment Canada, 2005, Shoreline Erosion caused by Boat Wake.

Fassbender, Judy L. and Ronald Winkler, 1992. Carbonate production and sediment transport in a marl lake of southeastern Wisconsin Limnol Oceanogr, 37(I). 1992. 184-191 0 1992, by the American Society of Limnology and Oceanography. Inc.

GDH Solutions. (2008). Major Lakes Recreational Marine Facilities Study. Kelowna, BC: Summit Environmental Consultants LTD. and JF Group.

GDH Solutions. (2011). RDNO Boat Launch study of Kalamalka Lake and Okanagan Lake. Kelowna, BC: Summit Environmental Consultants LTD. and Ipos Reid.

Grimes, D. J. 1980. Bacteriological water quality effects of hydraulically dredging contaminated upper Mississippi River bottom sediment. Appl. Environ. Microbiol. 39:782-789.

Haglund, Ann-Louise, Peter Lant, Erik To«rnblom and Lars Tranvik, 2003. Depth distribution of active bacteria and bacterial activity in lake sediment. FEMS Microbiology Ecology 46 (2003) 31^3

Hakanson, L. 1977. The influence of wind, fetch and water depth on the distribution of sediments in Lake Vanem, Sweden. Can. J. Earth Sci. 14: 397- 412

HayCo. (2009). *Kelowna Old Floating Pontoon Sinking - Technical Memo January 12, 2009 File V13201134 and February 13, 2009 File V13201184*.

Hilton, J., J.P. Lishman and P.V. Allen, 1986. The Dominant processes of sediment distribution and focusing in a small eutrophic, monomictic lake.

Howard, T.E., 1971. Report on Okanagan Lake Nutrient, Dissolved Oxygen and Transparency in Spring, 1970. B.C. Research, Division of Applied Biology

GDH Solutions with Summit Environmental and Ipsos Reid 2011. RDNO Boat Launch Study Kalamalka Lake and Okanagan Lake.

Jaakson, R., M.D. Buszunski, and D. Botting. 1990. Carrying capacity and lake recreation planning. The Michigan Riparian, November 1989. Pp. 11-12. 14.

Kusler, J.A. 1972. Carrying capacity controls for recreation water uses. Upper Great Lakes Regional Commission.

Larratt, H., 2001 Kalamalka Lake Water Quality Study Microflora, Water Quality and Thermal Profiles, 2001. Prepared for: City of Vernon, Lake Country/Oyama Improvement District, and B.C. Ministry of Environment

Larratt, H., 2005. Kalamalka Lake Water Quality Study Microflora, Water Quality and Thermal Profiles, 2005. Prepared for: City of Vernon, Lake Country/Oyama Improvement District, and B.C. Ministry of Environment

Larratt, H., 2010. District of Lake Country Source to Tap Assessment of the South Kalamalka Lake Intake – July 2010.

Larratt, H., 2011. Source Assessment of the Regional District of North Okanagan - Greater Vernon Water Utility North Kalamalka Lake Intake

Larratt, H., 2011 b. Kalamalka Lake Water Quality Study Microflora, Water Chemistry & Thermal Profiles, 2010.

Larratt, H. and J. Self, 2014. Kalamalka Lake Water Quality Study: Microflora, Water Chemistry & Thermal Profiles, 2013

Larratt H. and J. Self 2015 Kalamalka Lake Water Quality Study: Microflora, Water Chemistry & Thermal Profiles, 2014

Macdonald, Robie W. D. Patrick Shaw and Colin Gray, N.D. Contaminants in Lake Sediments and Fish. Department of Fisheries and Oceans Institute of Ocean Sciences Sidney, B.C., and Aquatic and Atmospheric Sciences Division, Environment Canada Vancouver, B.C. http://publications.gc.ca/collections/collection_2015/ec/En47-119-1999-4-eng.pdf

Mosisch, Thorsten D. and Angela H. Arthington, 1998. The impacts of power boating and water skiing on lakes and reservoirs March 1998 Volume 3, Issue 1 Lakes and Reservoirs Research and Management pg 1-17.

Osoyoos Lake Water Quality Society, 2016. On-line newsletter http://www.osoyooslake.ca/index.php/pollution.html.

Rajan, B., V. M. Varghese, and A. P. Pradeepkumar. 2011. Recreational boat carrying capacity of Vembanad Lake Ecosystem, Kerala, South India. Environmental Research, Engineering and Management 56:11–19.

Rose, Neil, L., David Morley, Peter G. Appleby, Richard W. Battarbee, Tiiu Alliksaar, Piero Guilizzoni Erik Jeppesen, Atte Korhola, Jaan-Mati Punning, 2011. Sediment accumulation rates in European lakes since AD 1850: trends, reference conditions and exceedence Journal of Paleolimnology April 2011, Volume 45, Issue 4, 447–46.

Schleppe, J. and A. Cormano. Kalamalka Lake Aquatic Habitat Index. Ecoscape Environmental Consultants Ltd. Project file: 12-950. November 2012. Prepared for Okanagan Collaborative Conservation Program.

St. John, B.E. 1973 . PRELIMINARY REPORT N0.18 The Limnogeology of the Okanagan Mainstem Lakes PREPARED FOR THE OKANAGAN STUDY COMMITTEE CANADA - BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT TASK 121

Threinen, C.W. 1964. An analysis of space demands for water and shore. Wisconsin Conservation Department.

Warbach, J.D., M.A. Wyckoff, G.E. Fisher, P. Johnson, and G. Gruenwald. 1994. Regulating keyhole development: Carying capacity analysis and ordinances providing lake access regulations. Planning and Zonging Centger, Inc.

Wagner, Kenneth, J. 1991. Assessing impacts of motorized watercraft on lakes: Issues and perceptions. Proceedings of a Nationhal Conference on Enhancing States' Lake Management Programs. Northeastern Illinois Planning Commission.

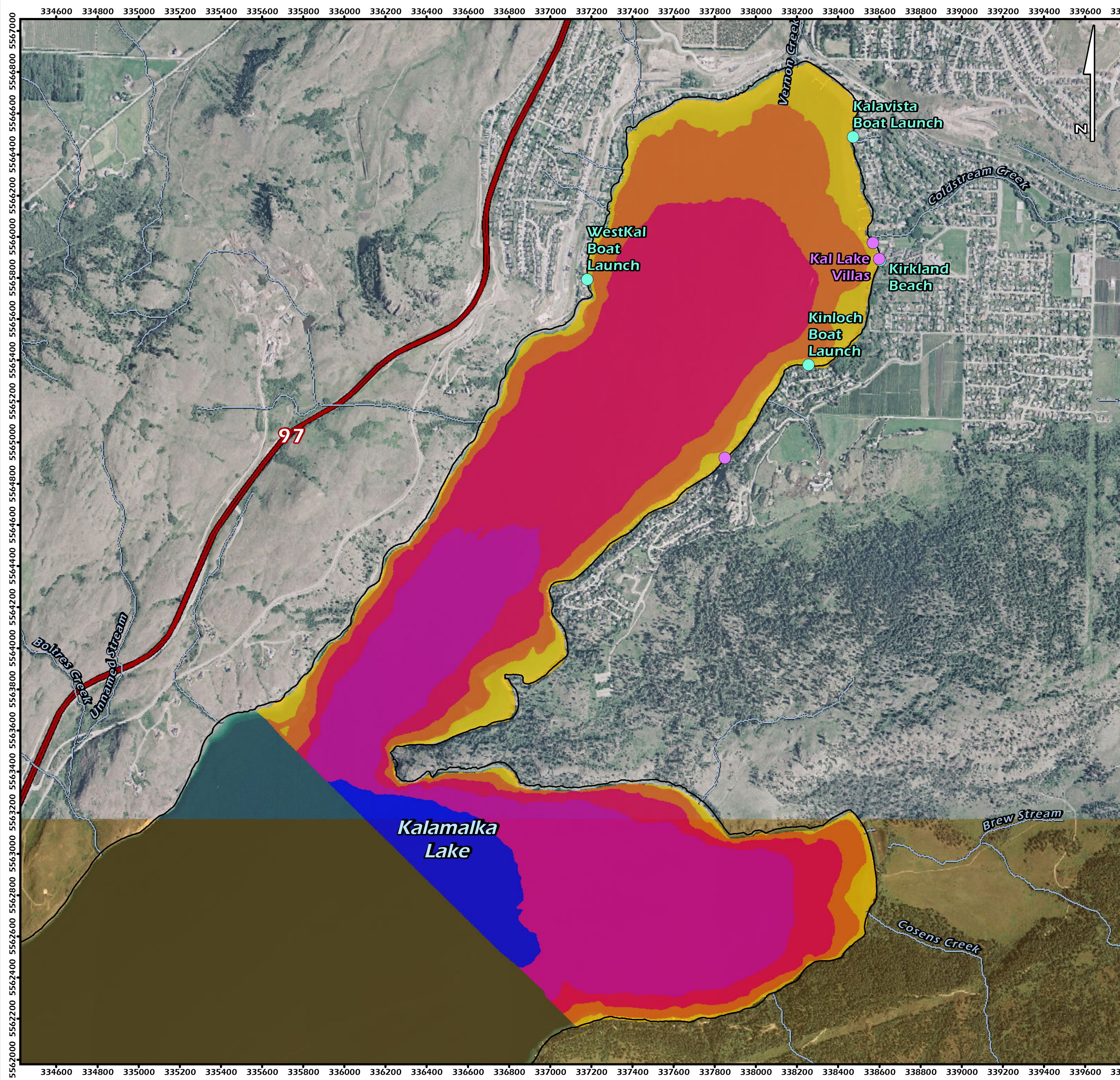
Walker, I. R., E. D. Reavie, S. Palmer, and R. N. Nordin, 1993. A palaeoenvironmental assessment of human impact on Wood Lake, Okanagan Valley, British Columbia. Quaternary International 20: 51-70.

Wiik, Emma, Helen Bennion, Carl D. Sayer, Thomas A. Davidson, Suzanne McGowan, Ian R. Patmore and Stewart J. Clarke, 2015. Ecological sensitivity of marl lakes to nutrient enrichment: evidence from Hawes Water, UK. Freshwater Biology Volume 60, Issue 11, November 2015 Pages 2226–2247.

Wetzel, Robert, G., 2007 Limnology, Lake and River Systems, Third Edition. Academic Press, San Diego.

MAPS

Bathymetry Maps

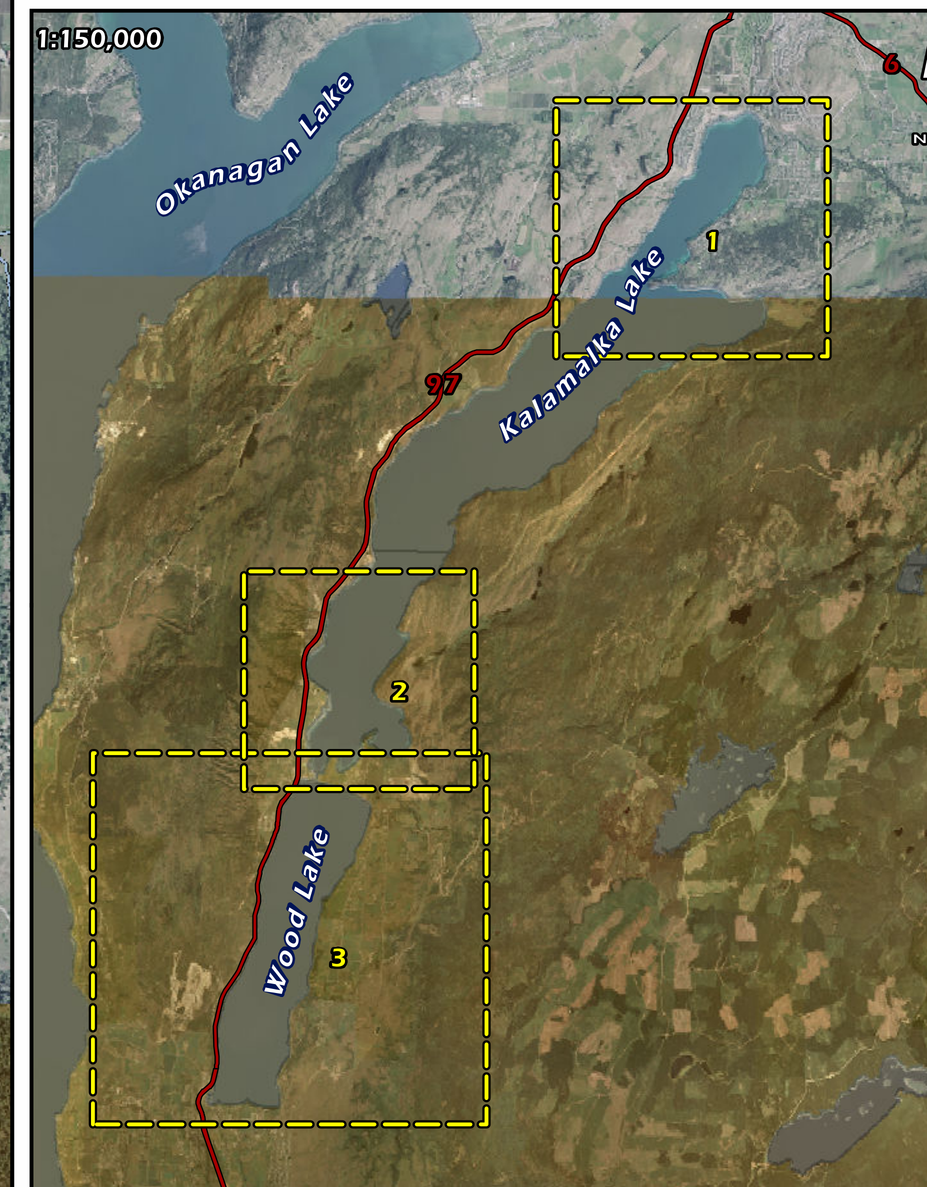


Mapsheet 1: North Kalamalka Lake

Bathymetry

LEGEND

Places	Major Highway	Lake Depths
Marina	Streams	0 - 7 m
Boat Launch	Mapsheets	7 - 29 m
	Lake	29 - 51 m
		51 - 74 m
		74 -88 m



0 240 480 960 1,440 1,920 Meters

DISCLAIMER

The data displayed in this figure is for conceptual purposes only and should not be interpreted as a legal survey or for legal purposes.

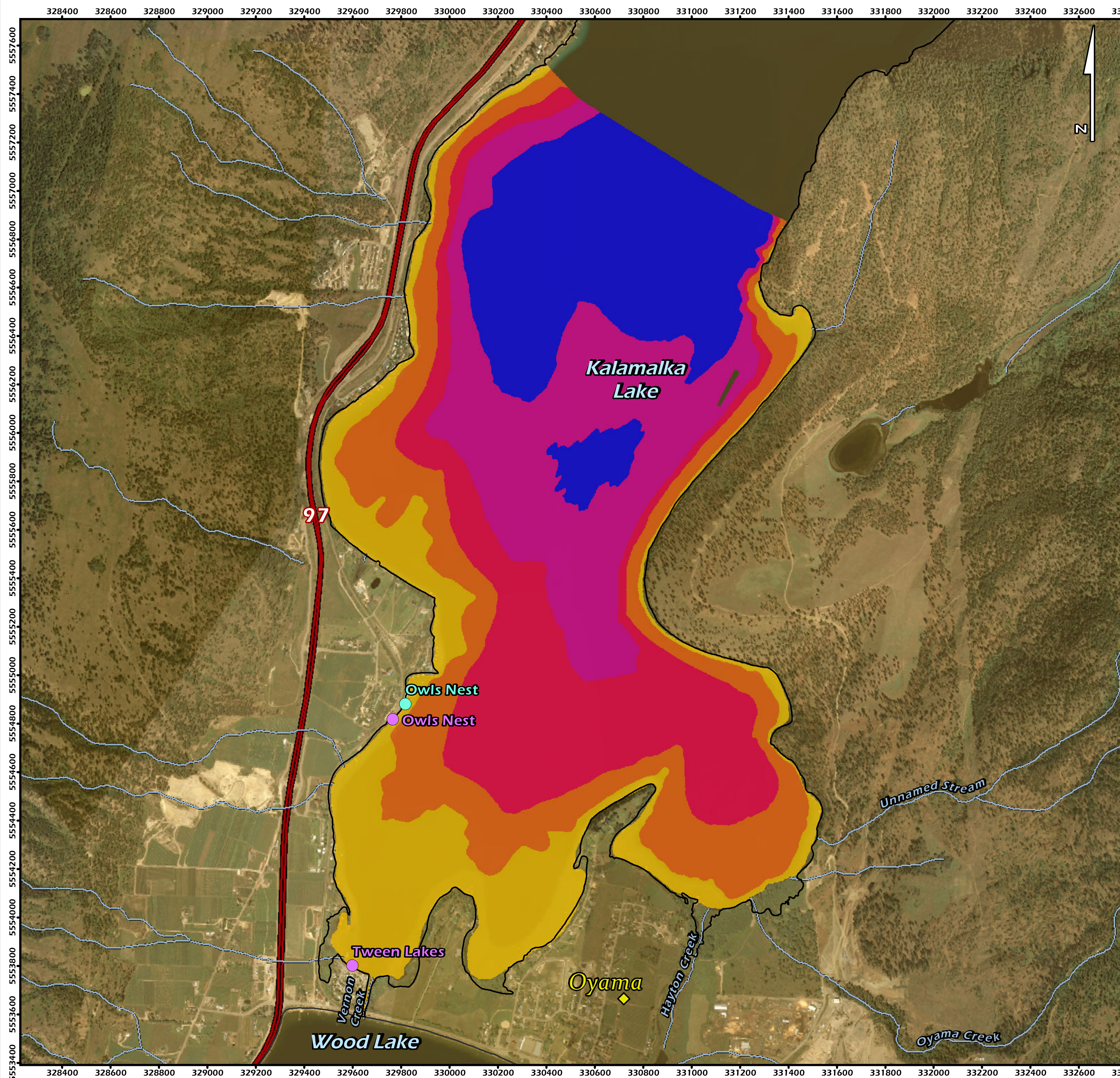
Mapsheet 2: South Kalamalka Lake

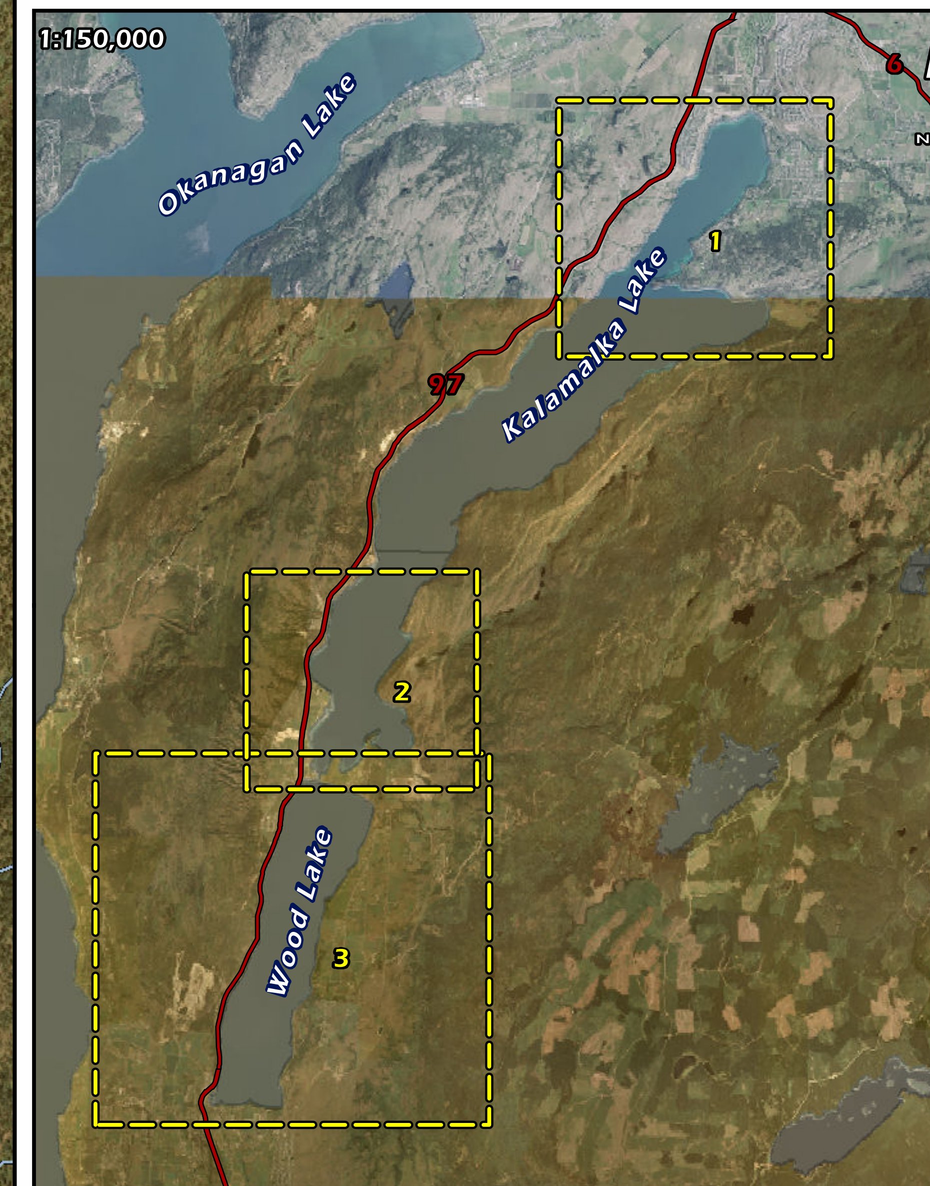
Bathymetry

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake

Lake Depths
- 0 - 6 m
- 6 - 30 m
- 30 - 42 m
- 42 - 58 m
- 58 - 102 m





0 205 410 820 1,230 1,640 Meters

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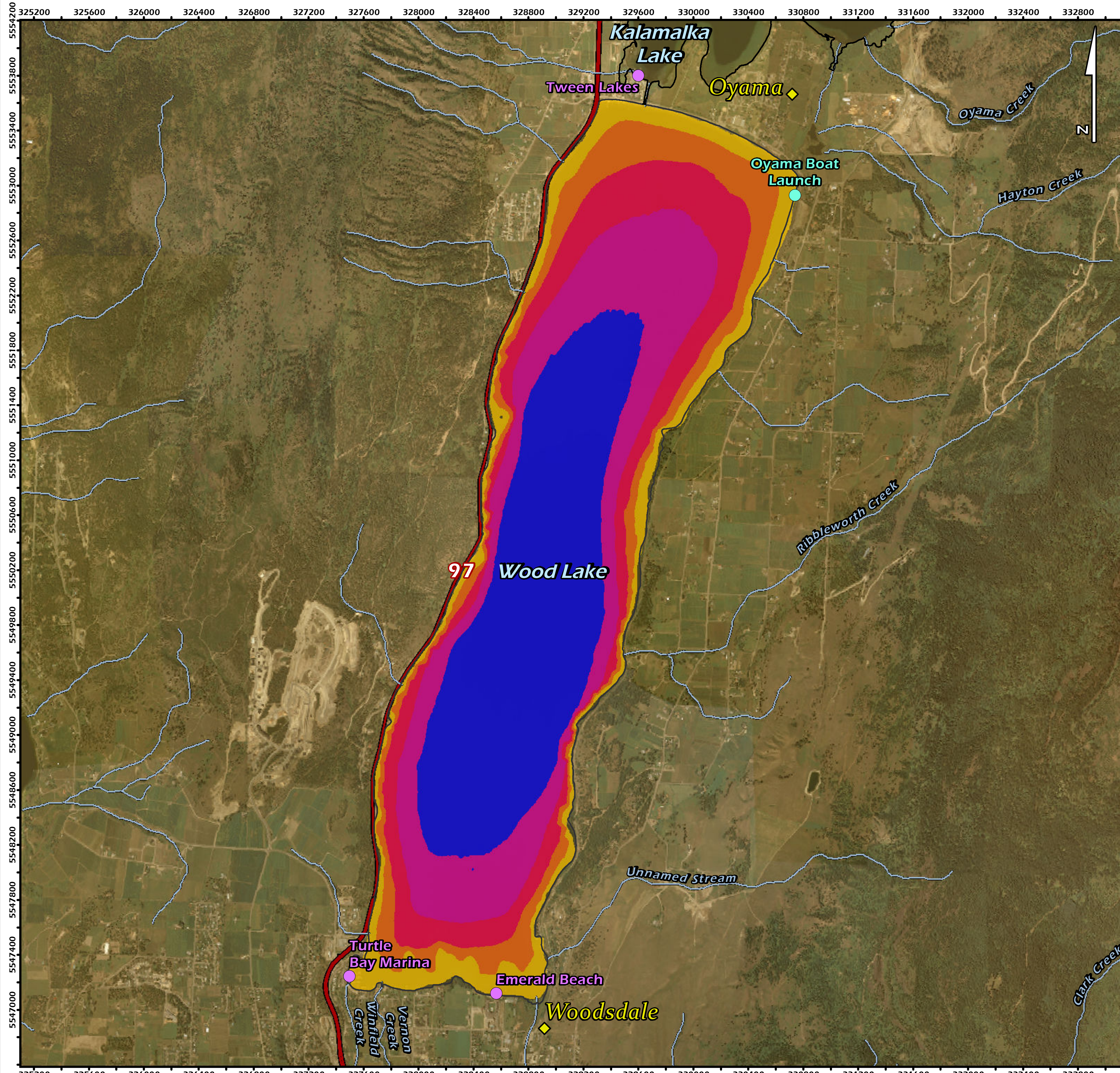


Mapsheet 3: Wood Lake

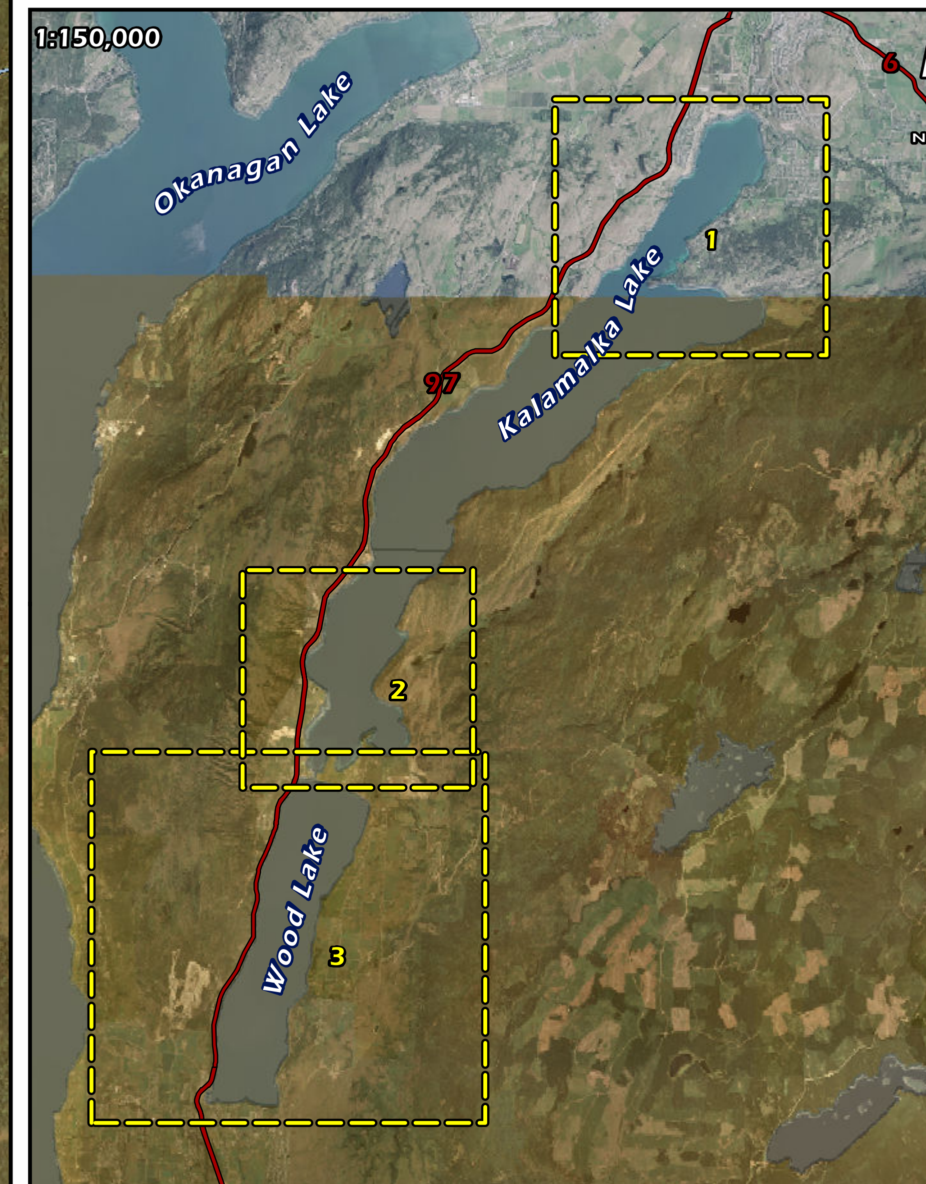
Bathymetry

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake

Lake Depths

- 0 - 8 m
- 8 - 15 m
- 15 - 21 m
- 21 - 27 m
- 27 - 33 m



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER

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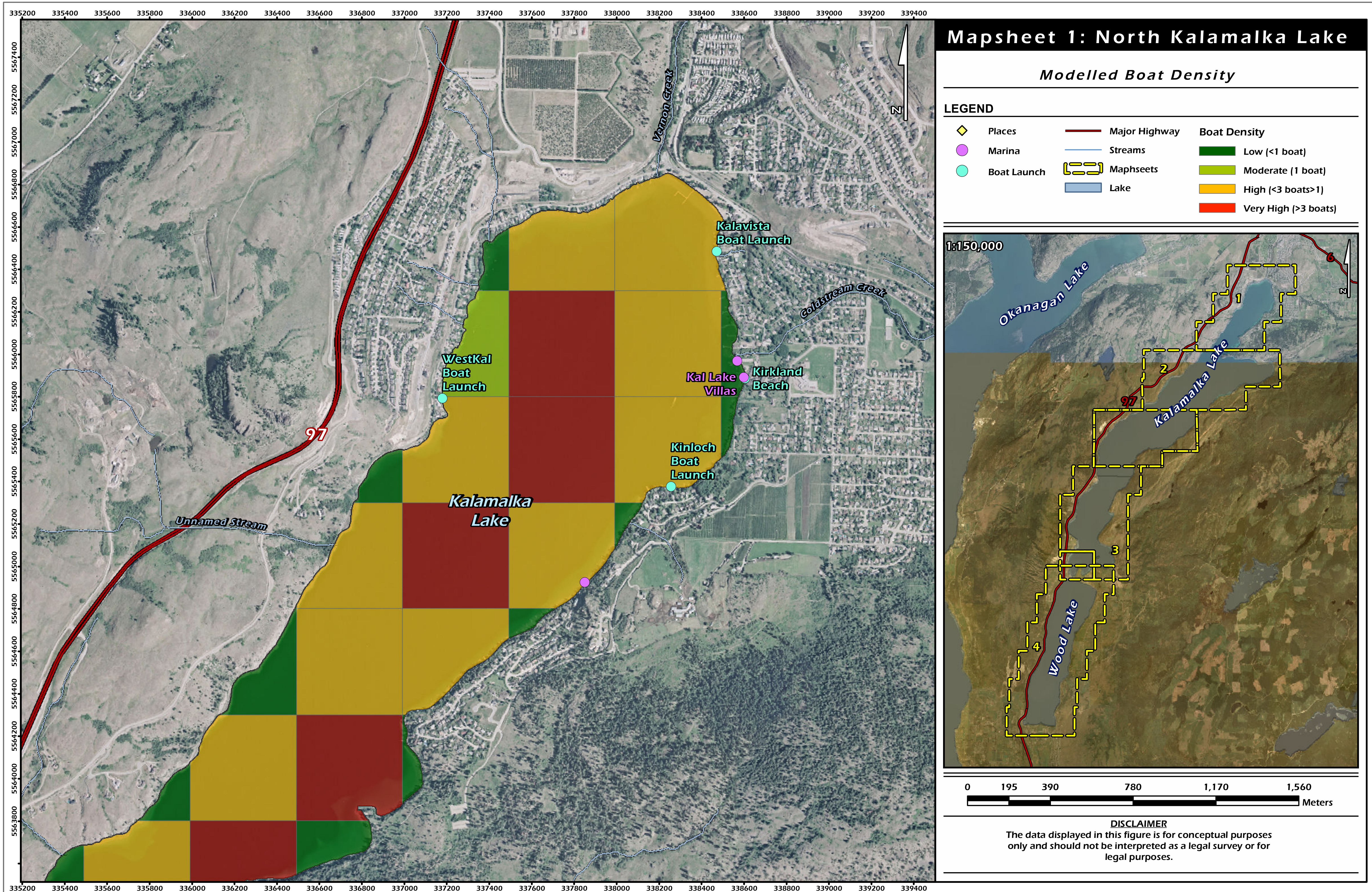
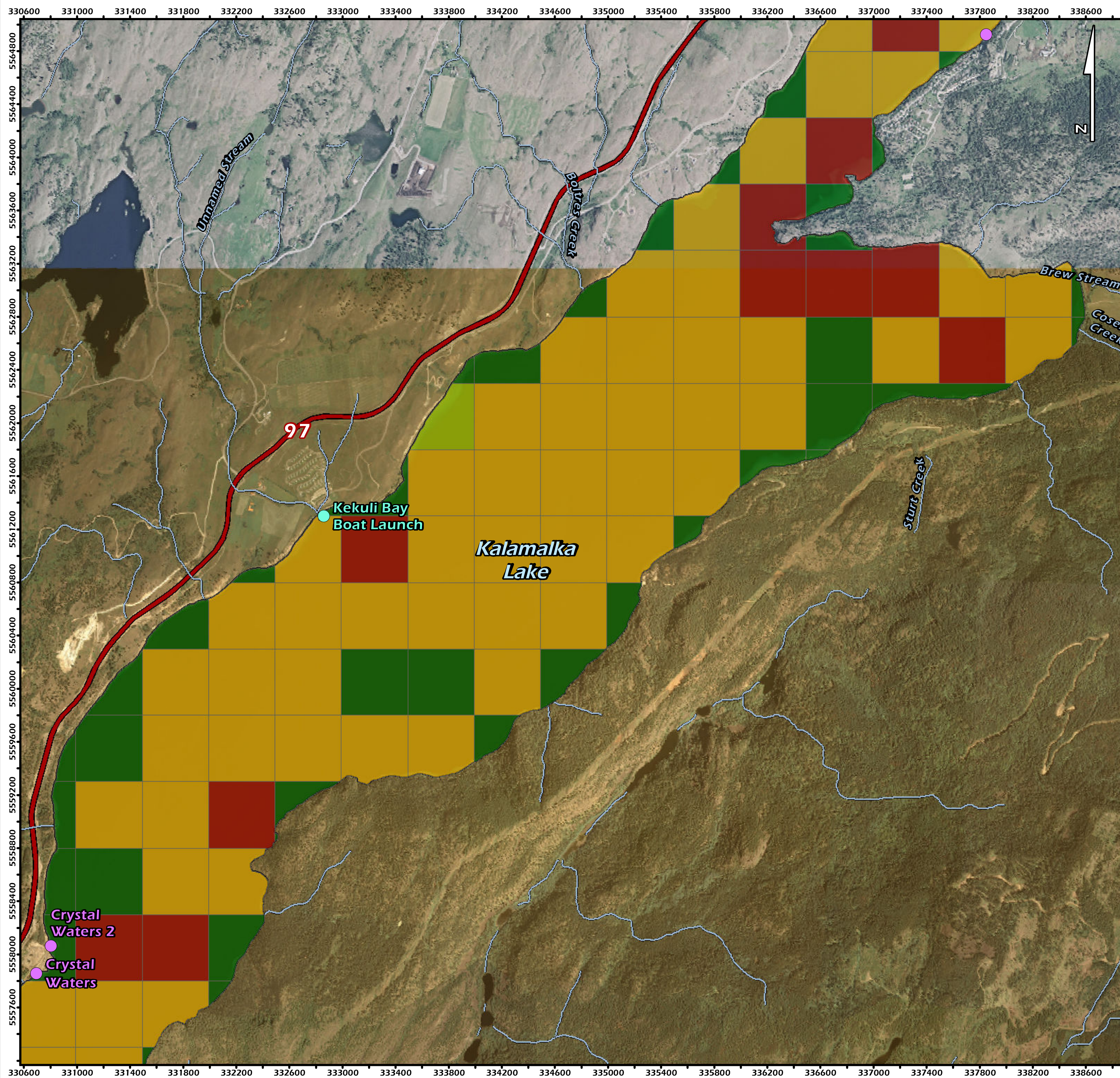
Boat Density Maps


Mapsheet 1: North Kalamalka Lake
Modelled Boat Density
LEGEND
Places
Marina
Boat Launch
Major Highway
Streams
Mapsheets
Lake
Boat Density
Low (<1 boat)
Moderate (1 boat)
High (<3 boats>1)
Very High (>3 boats)
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
97
0 195 390 780 1,170 1,560
Meters
DISCLAIMER
The data displayed in this figure is for conceptual purposes only and should not be interpreted as a legal survey or for legal purposes.
Kalavista Boat Launch
Coldstream Creek
Vernon Creek
WestKal Boat Launch
Kal Lake Villas
Kirkland Beach
Kinloch Boat Launch
Kalamalka Lake
Unnamed Stream

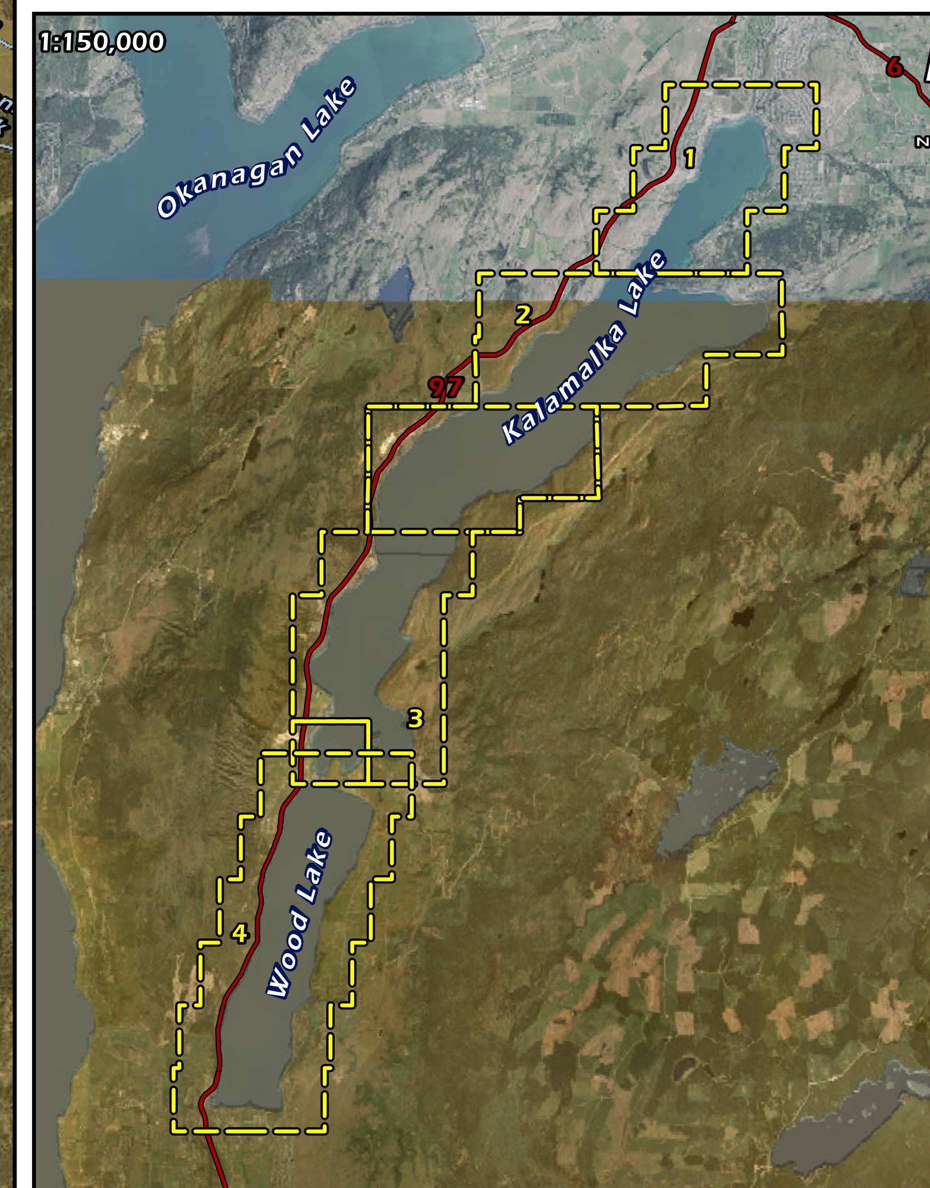


Mapsheet 2: Mid Kalamalka Lake

Modelled Boat Density

LEGEND

Places	Major Highway	**Boat Density**
Marina	Streams	Low (<1 boat)
Boat Launch	Mapsheets	Moderate (1 boat)
	Lake	High (<3 boats>1)
		Very High (>3 boats)



0 375 750 1,500 2,250 3,000
Meters

DISCLAIMER

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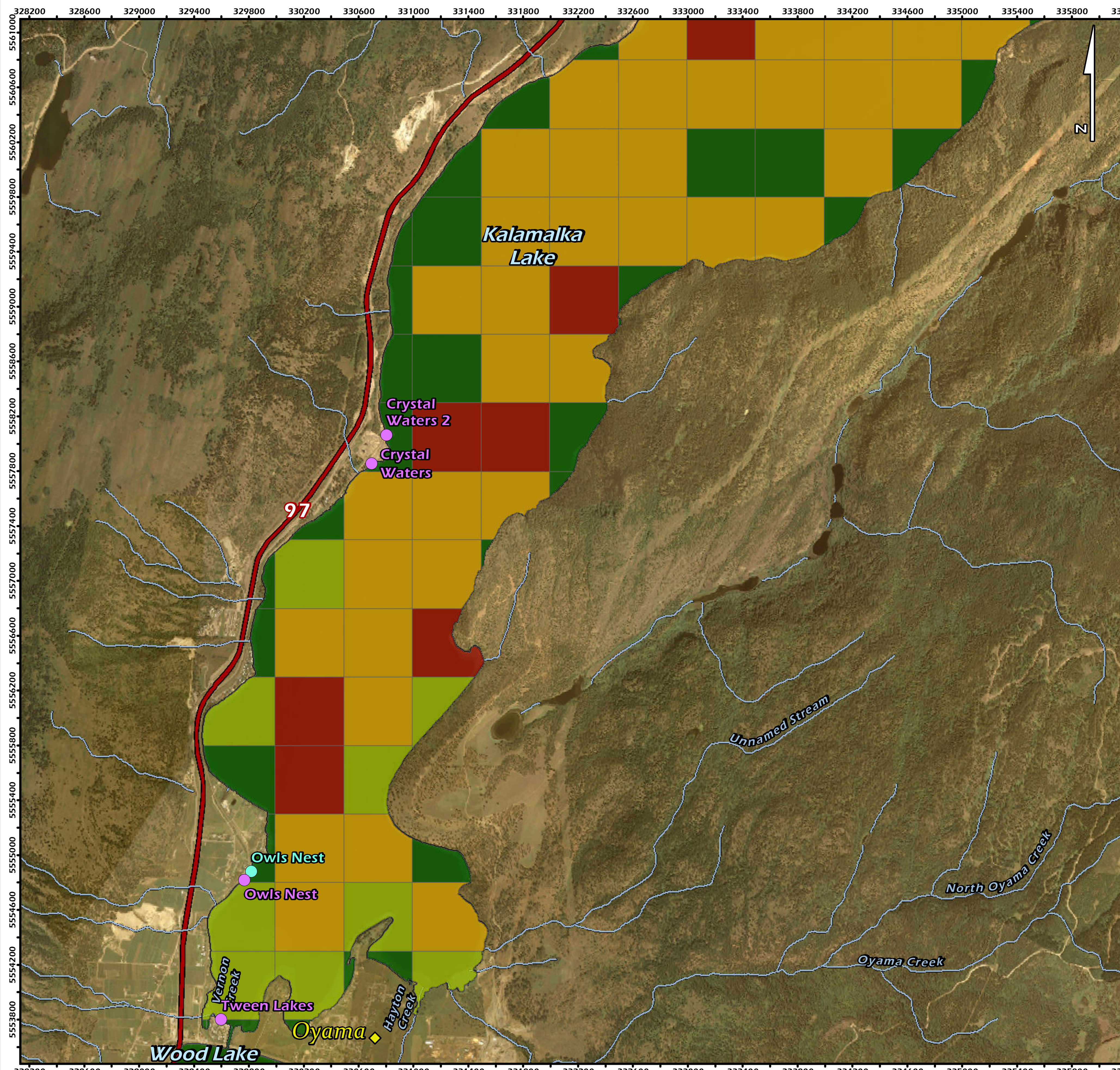


Mapsheet 3: South Kalamalka Lake

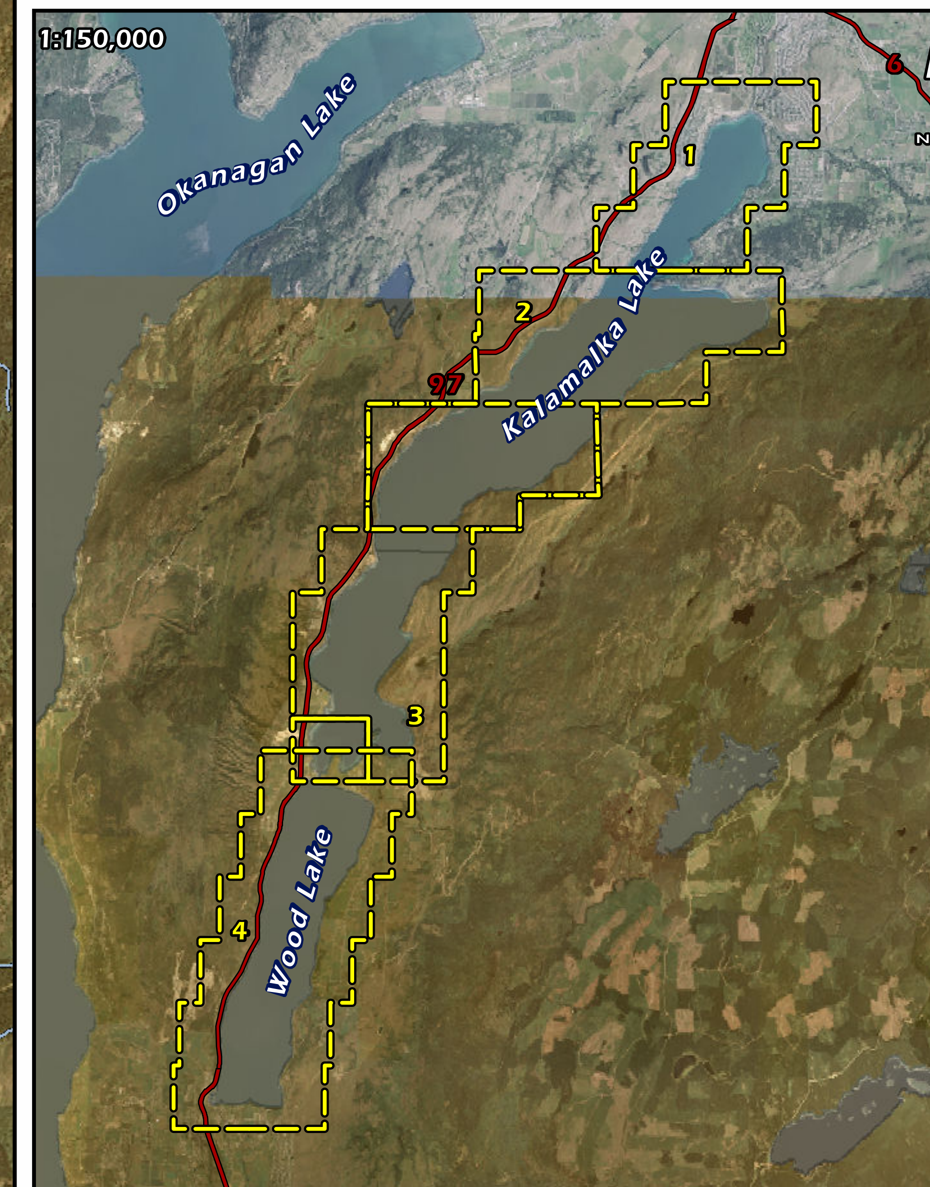
Modelled Boat Density

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake

Boat Density

- Low (<1 boat)
- Moderate (1 boat)
- High (<3 boats>1)
- Very High (>3 boats)



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER

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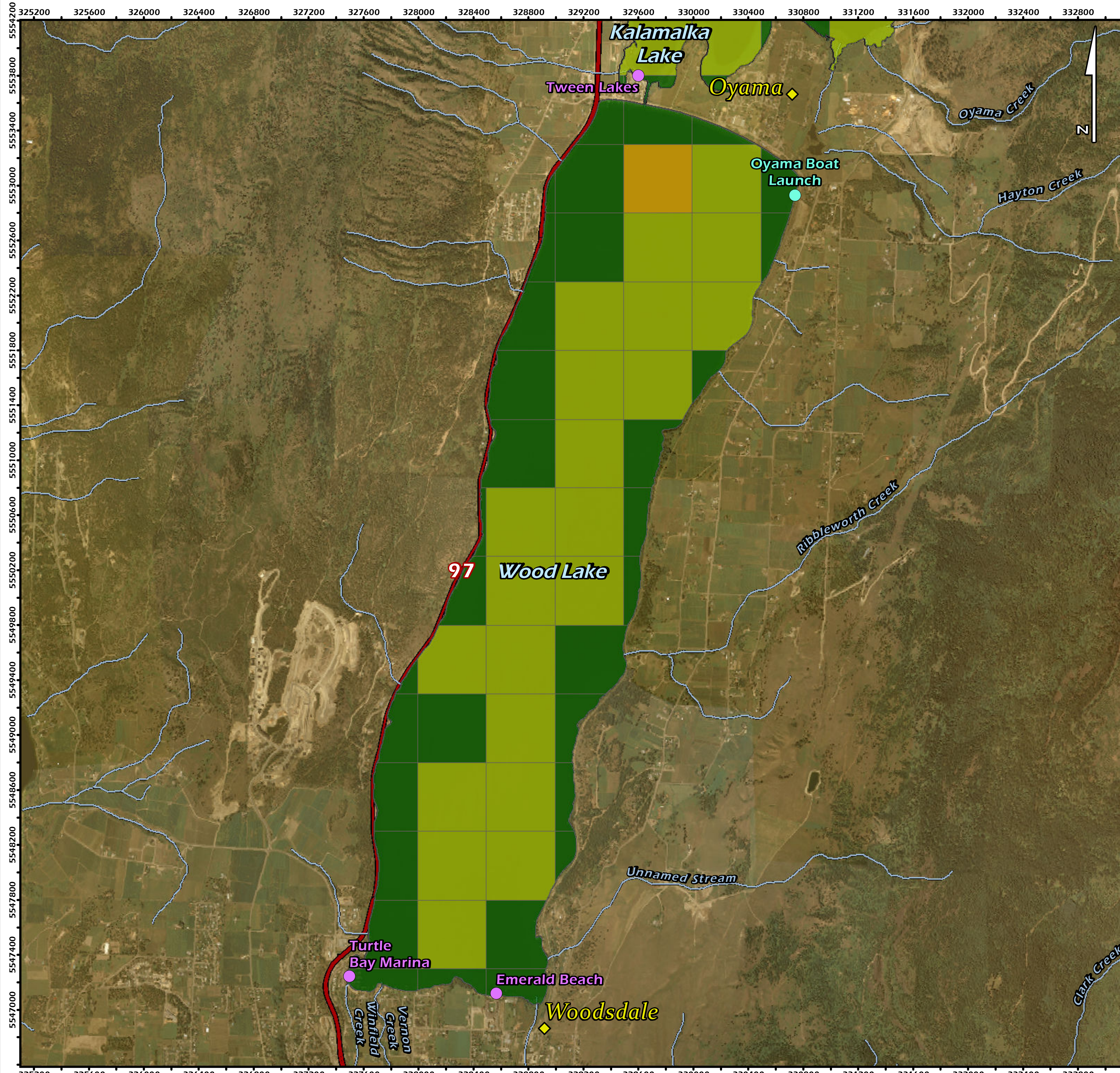
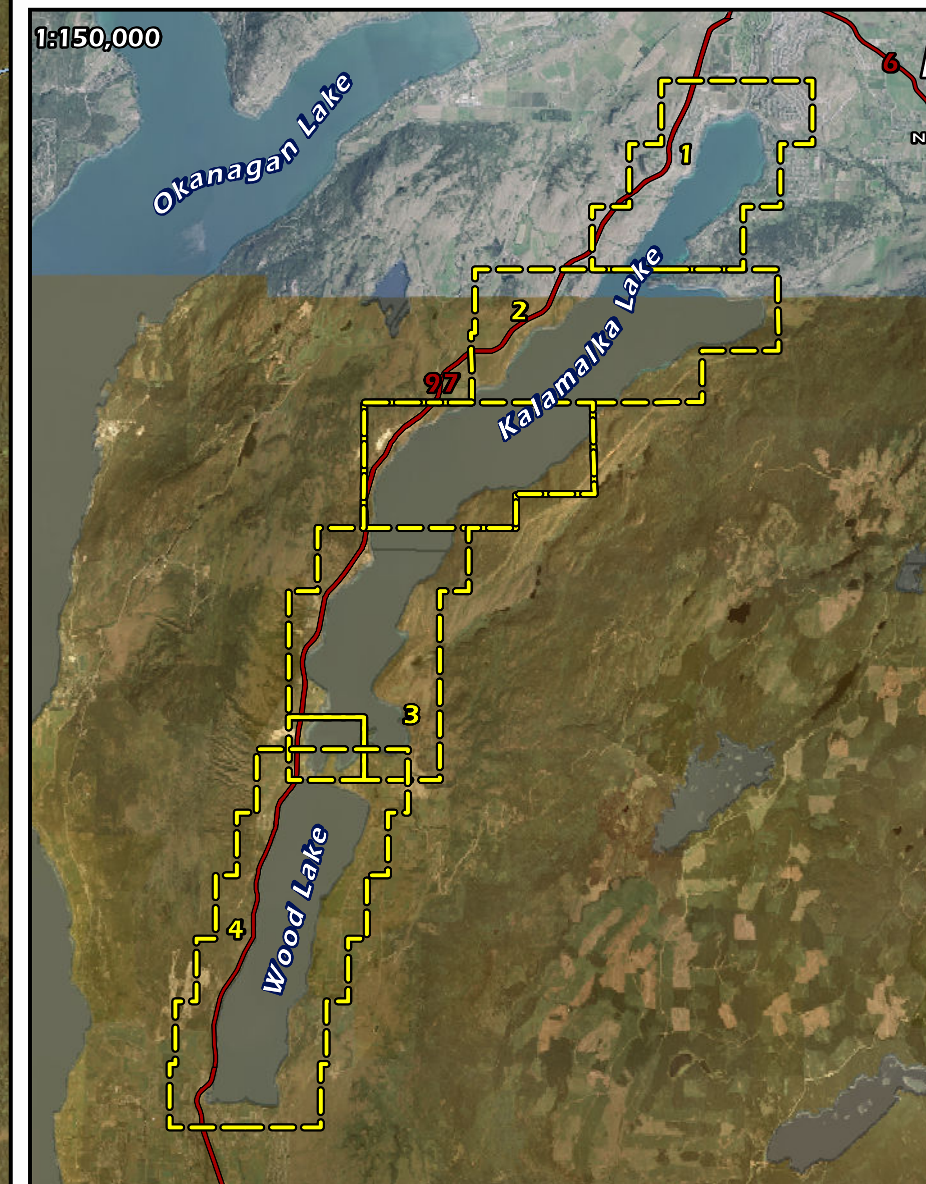


Mapsheet 4: Wood Lake

Modelled Boat Density

LEGEND

Places	Major Highway	**Boat Density**
Marina	Streams	Low (<1 boat)
Boat Launch	Mapsheets	Moderate (1 boat)
	Lake	High (<3 boats>1)
		Very High (>3 boats)



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER
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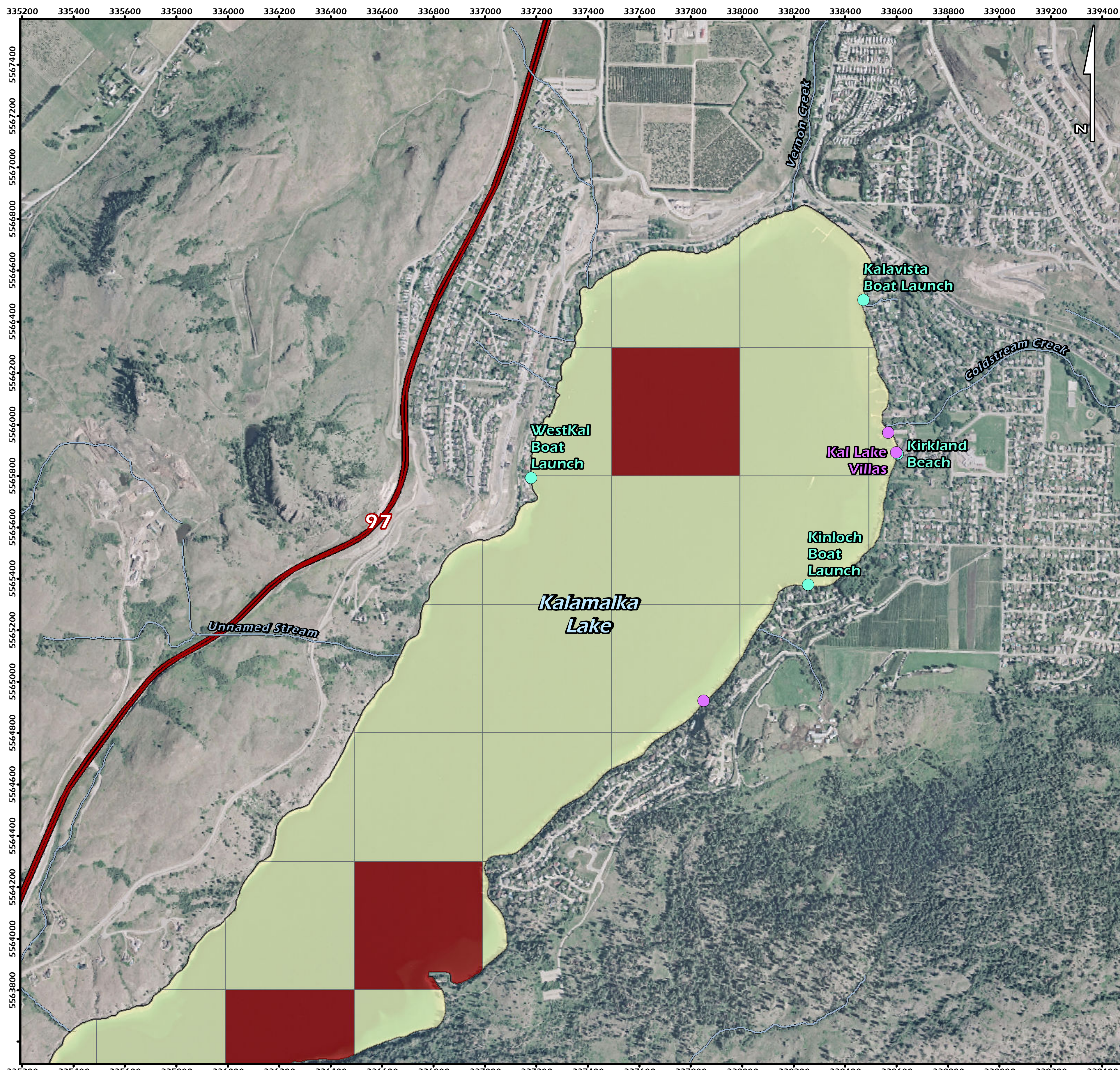
Carrying Capacity Maps

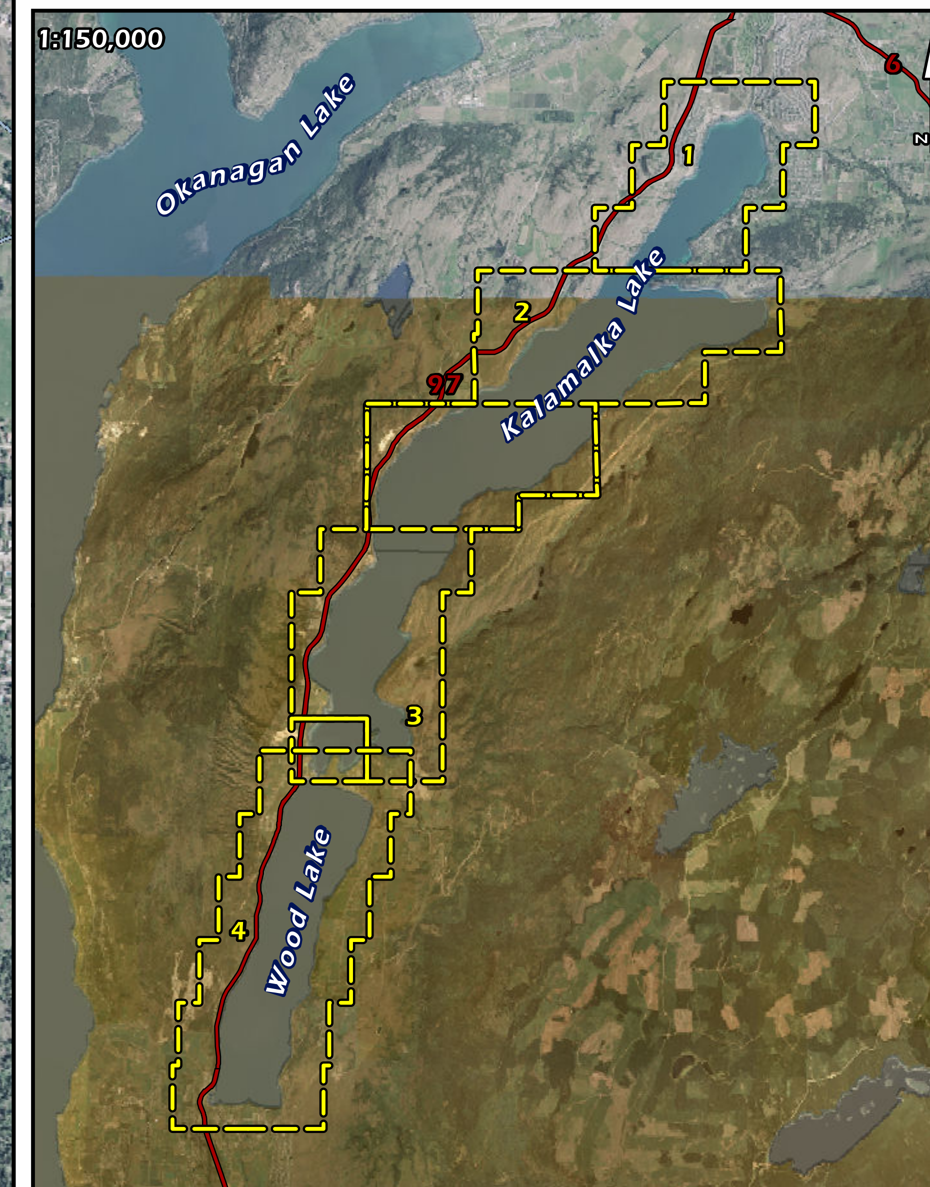
Mapsheet 1: North Kalamalka Lake



Modelled Carrying Capacity

LEGEND

Places	Major Highway	Exceeds Carrying Capacity
Marina	Streams	Under Carrying Capacity
Boat Launch	Mapseets	
	Lake	



0 195 390 780 1,170 1,560
Meters

DISCLAIMER
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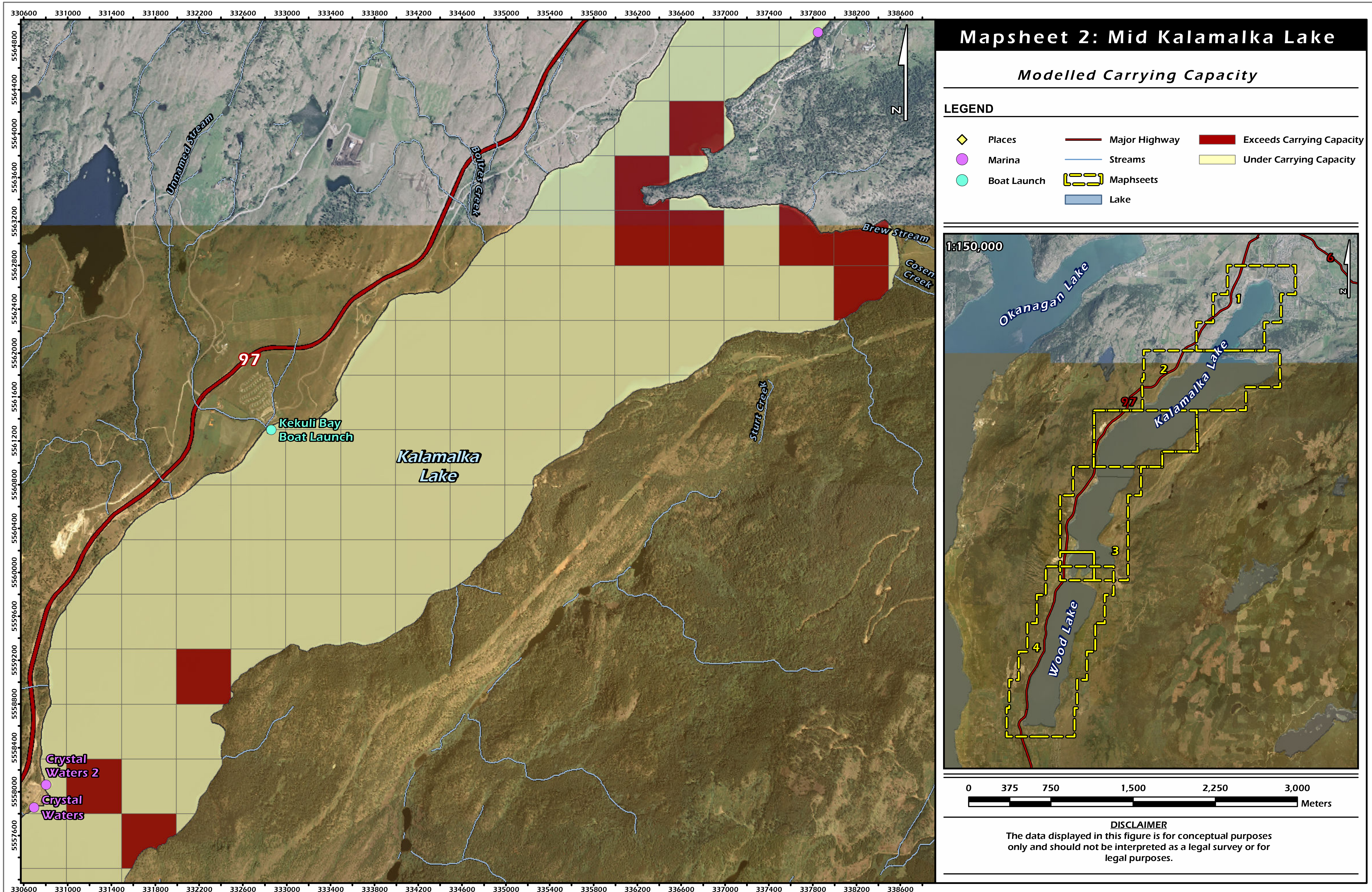
Mapsheet 2: Mid Kalamalka Lake
Modelled Carrying Capacity
LEGEND
Places
Marina
Boat Launch
Major Highway
Streams
Mapseets
Lake
Exceeds Carrying Capacity
Under Carrying Capacity
Unnamed Stream
Boltres Creek
Brew Stream
Cosen Creek
Sturt Creek
97
Kekuli Bay Boat Launch
Kalamalka Lake
Crystal Waters 2
Crystal Waters
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
1
2
3
4
6
N
0
375
750
1,500
2,250
3,000
Meters
DISCLAIMER
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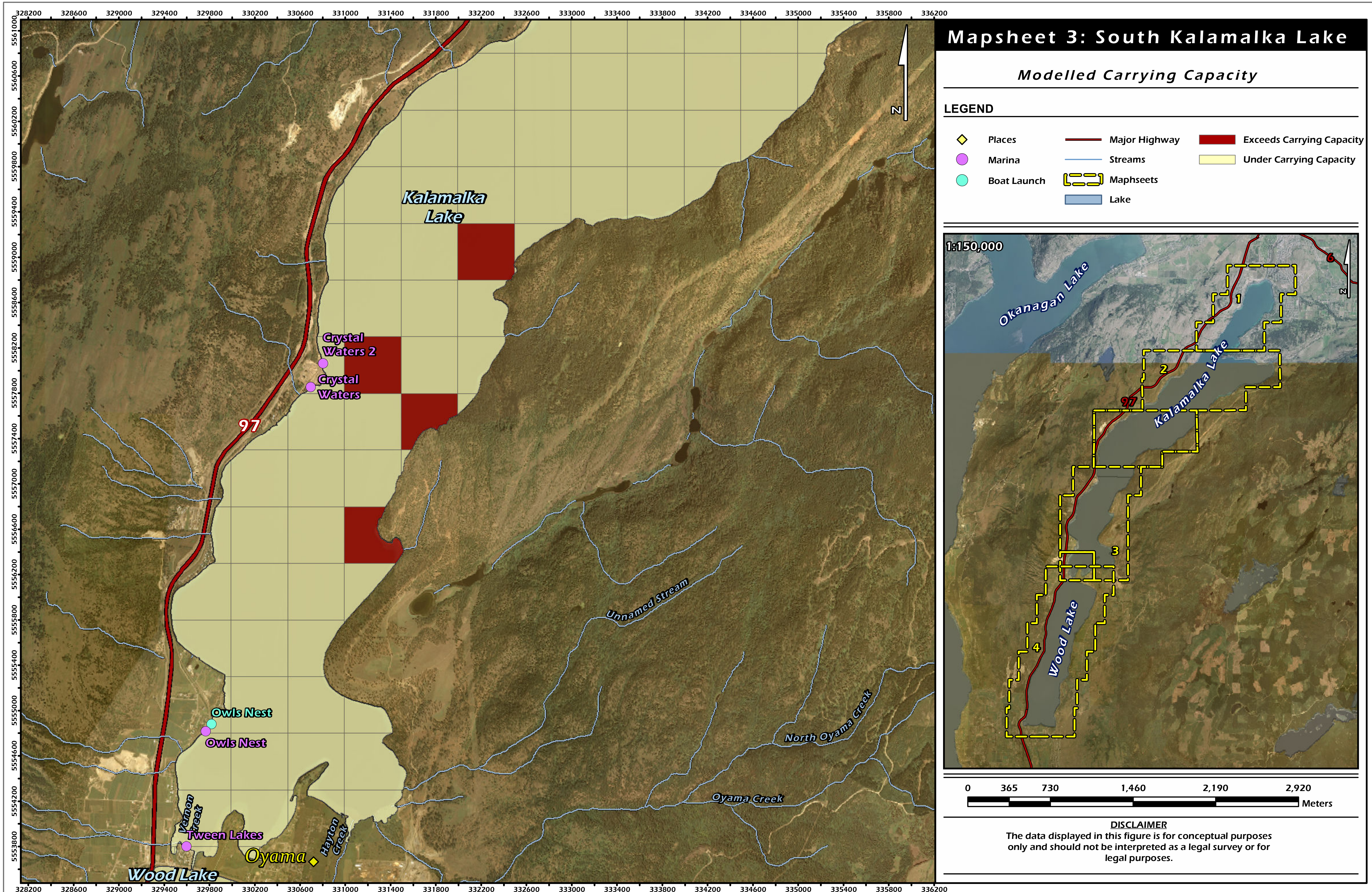
Mapsheet 3: South Kalamalka Lake
Modelled Carrying Capacity
LEGEND
Places
Marina
Boat Launch
Major Highway
Streams
Maphseets
Lake
Exceeds Carrying Capacity
Under Carrying Capacity
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
1
2
3
4
6
97
N
0
365
730
1,460
2,190
2,920
Meters
DISCLAIMER
The data displayed in this figure is for conceptual purposes only and should not be interpreted as a legal survey or for legal purposes.
Kalamalka Lake
Crystal Waters 2
Crystal Waters
97
Owls Nest
Owls Nest
Tween Lakes
Vernon Creek
Hayton Creek
Oyama
Wood Lake
Unnamed Stream
North Oyama Creek
Oyama Creek
328200
328600
329000
329400
329800
330200
330600
331000
331400
331800
332200
332600
333000
333400
333800
334200
334600
335000
335400
335800
336200
5561000
5560600
5560200
5559800
5559400
5559000
5558600
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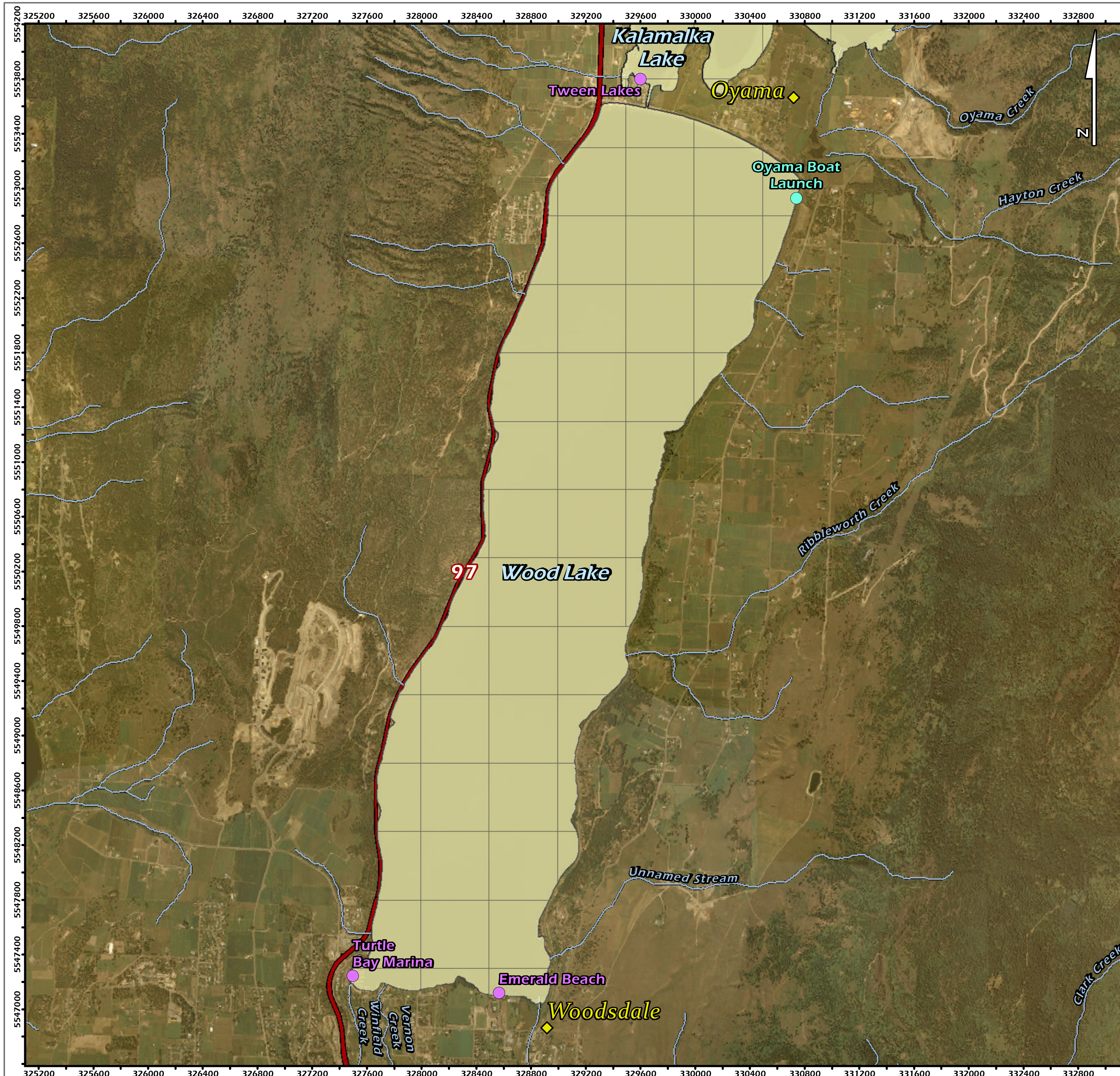
5557400
5557000
5556600
5556200
5555800
5555400
5555000
5554600
5554200
5553800

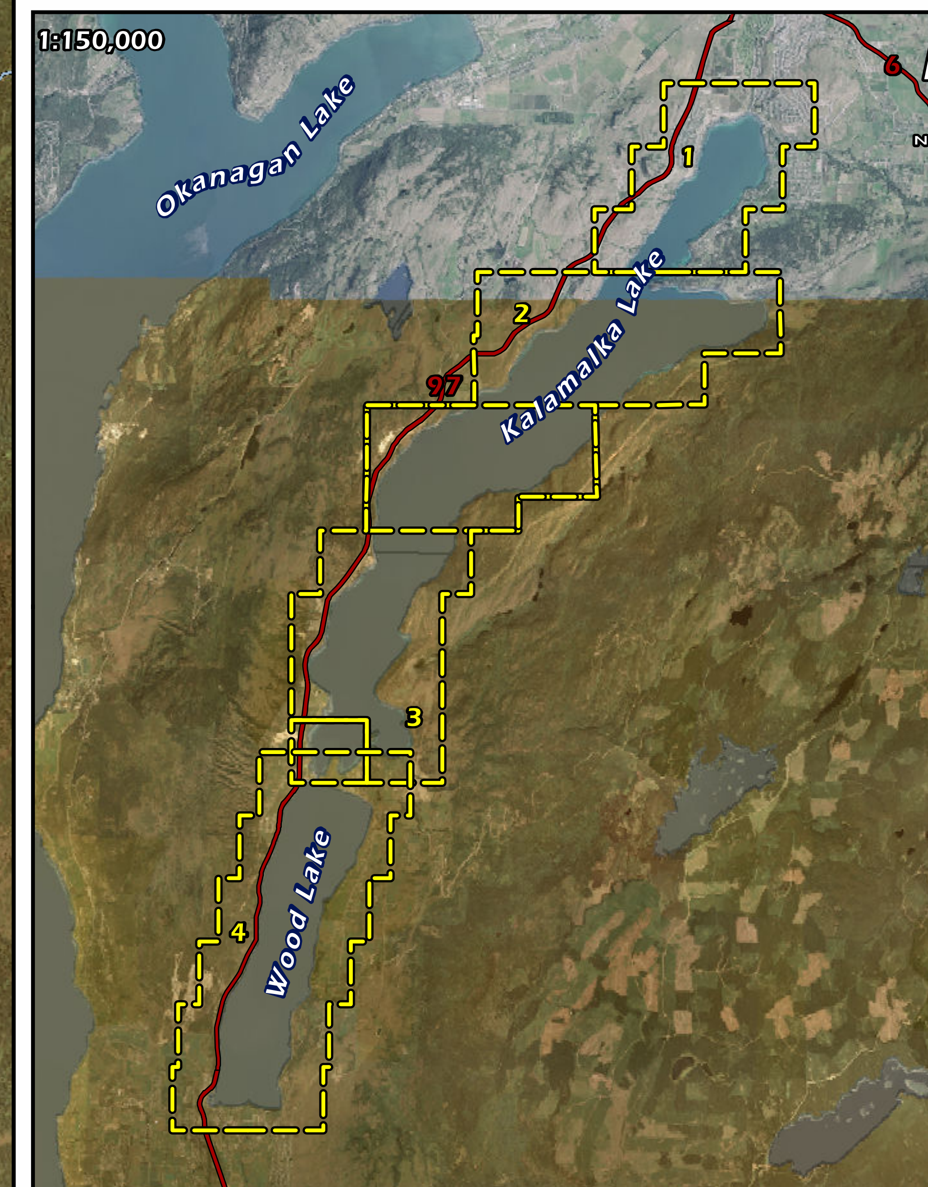


Mapsheet 4: Wood Lake

Modelled Carrying Capacity

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Maphseets
- Lake
- Exceeds Carrying Capacity
- Under Carrying Capacity



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER

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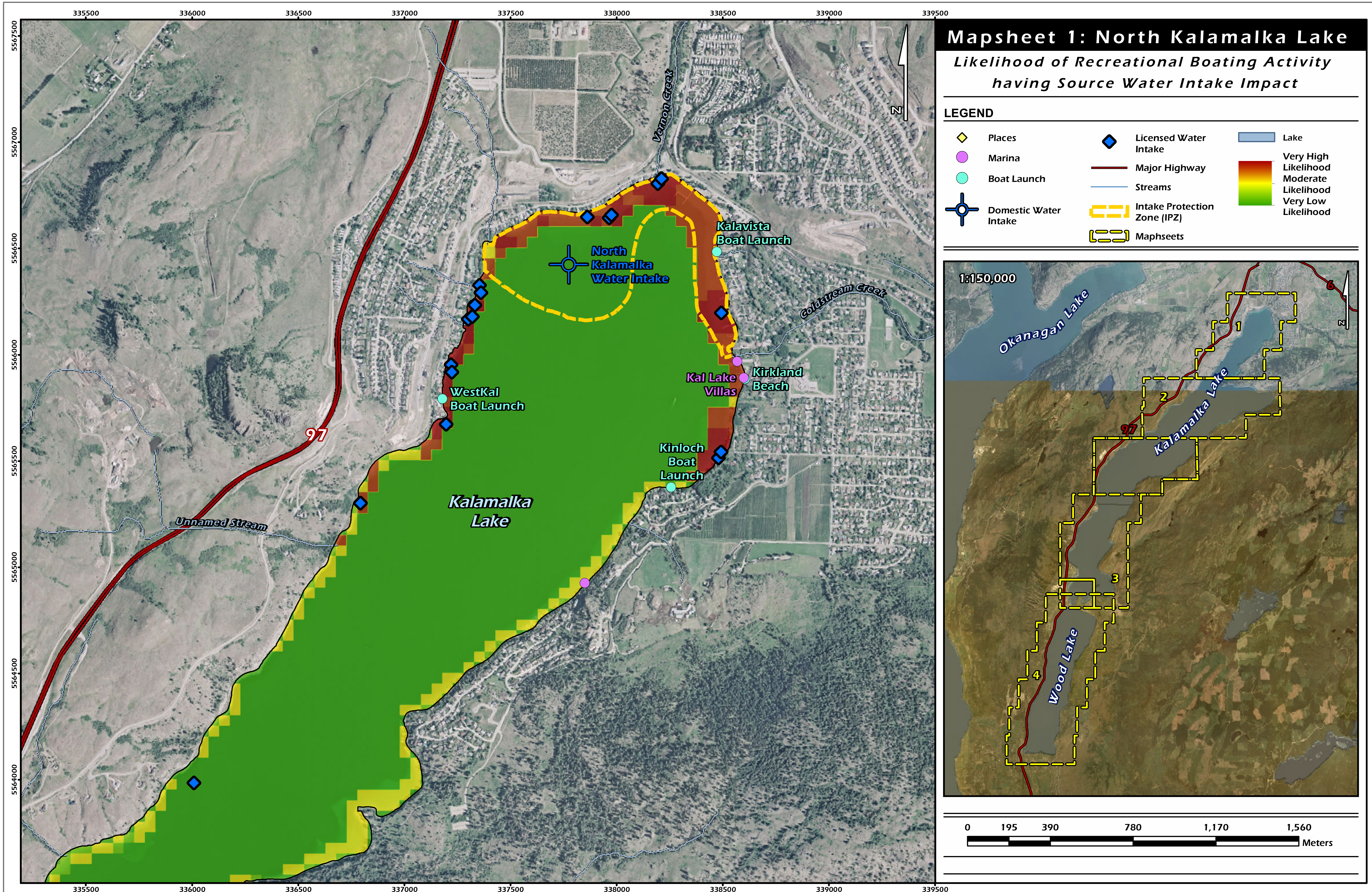
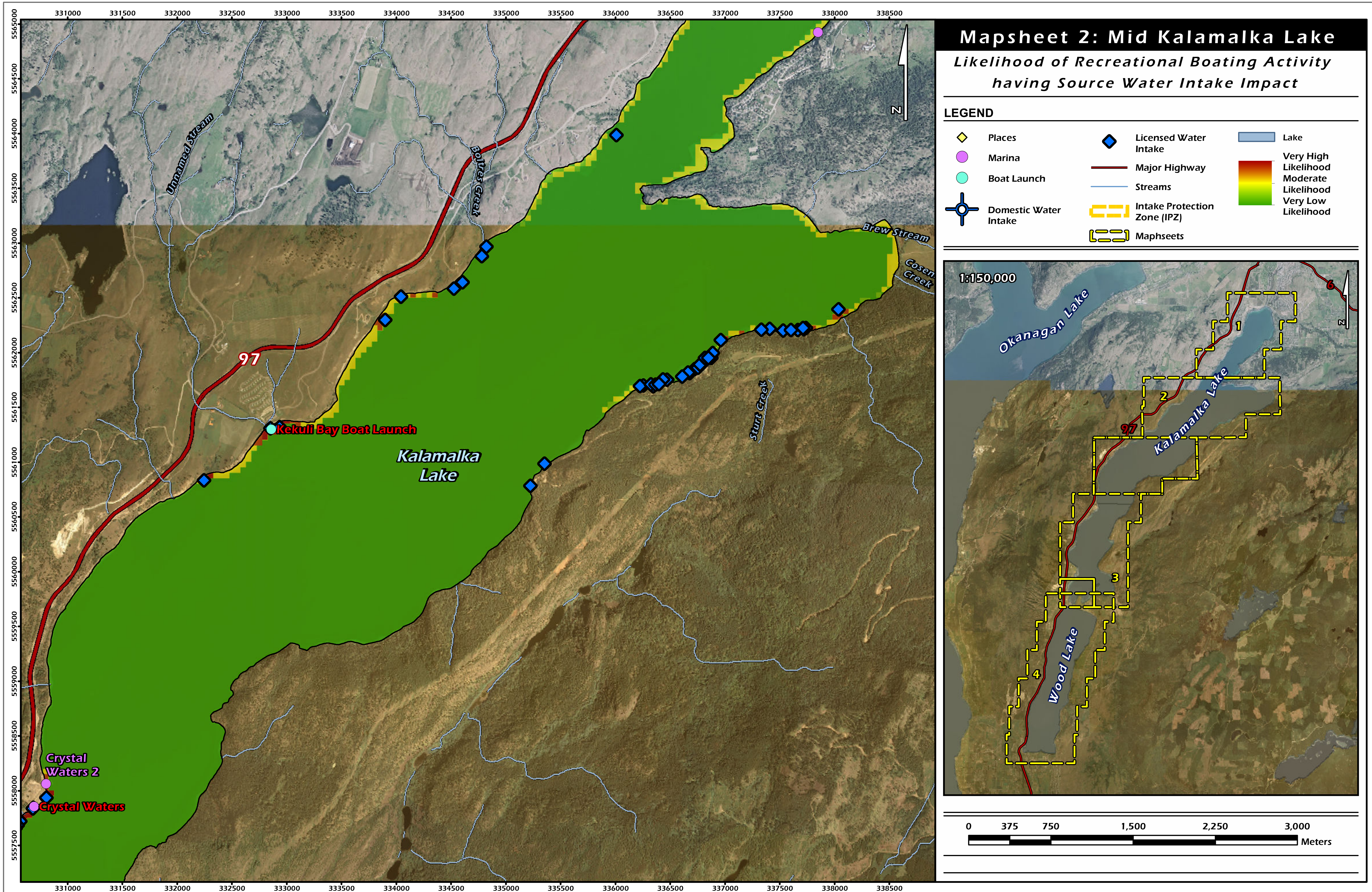
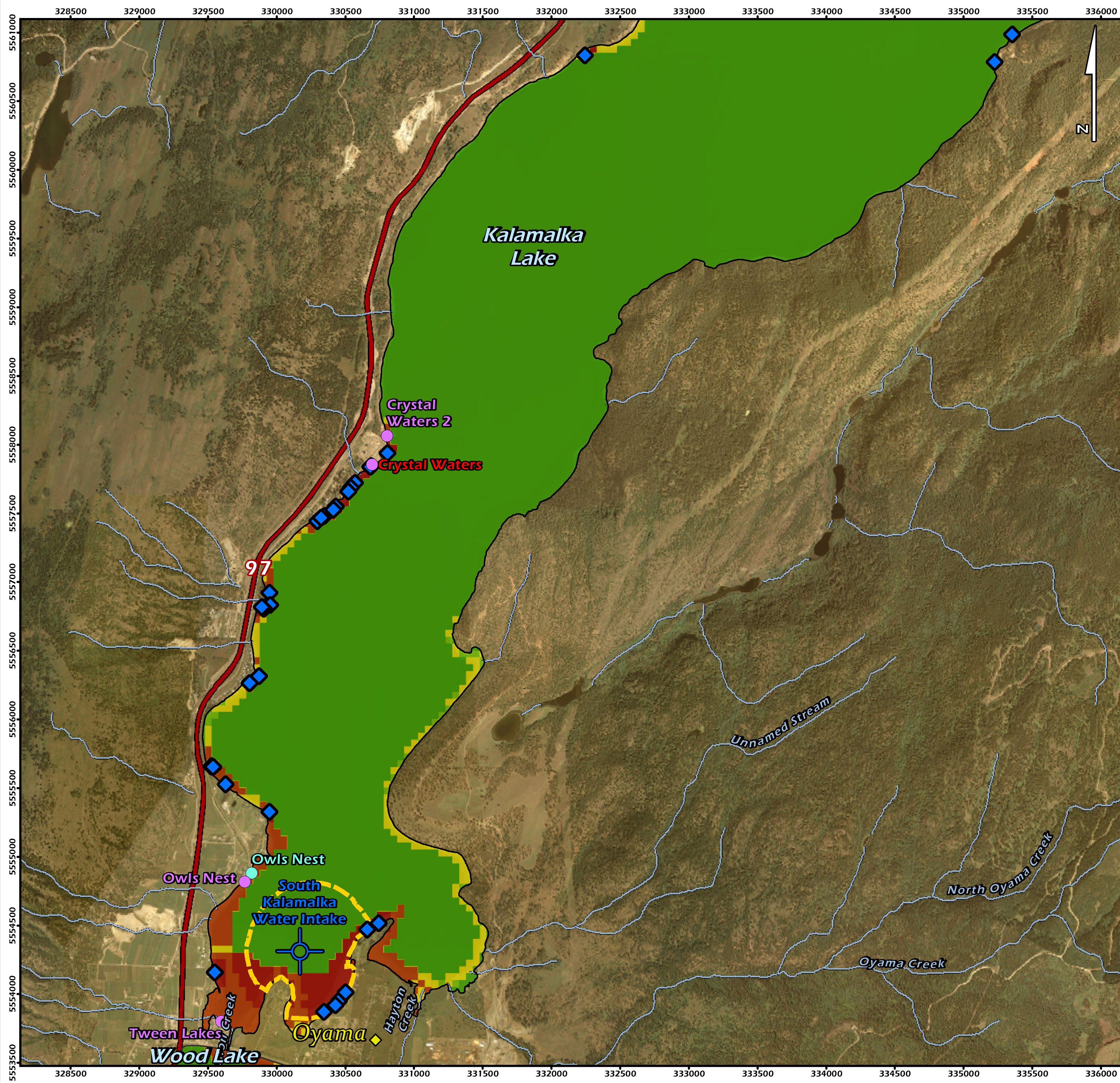
Source Likelihood Maps



Mapsheet 1: North Kalamalka Lake
Likelihood of Recreational Boating Activity having Source Water Intake Impact
LEGEND
Places
Marina
Boat Launch
Domestic Water Intake
Licensed Water Intake
Major Highway
Streams
Intake Protection Zone (IPZ)
Maphseets
Lake
Very High Likelihood
Moderate Likelihood
Very Low Likelihood
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
0 195 390 780 1,170 1,560
Meters
North Kalamalka Water Intake
Kalavista Boat Launch
Coldstream Creek
Vernon Creek
Kirkland Beach
Kal Lake Villas
WestKal Boat Launch
Kinloch Boat Launch
Unnamed Stream
97


Mapsheet 2: Mid Kalamalka Lake
Likelihood of Recreational Boating Activity having Source Water Intake Impact
LEGEND
Places
Marina
Boat Launch
Domestic Water Intake
Licensed Water Intake
Major Highway
Streams
Intake Protection Zone (IPZ)
Maphseets
Lake
Very High Likelihood
Moderate Likelihood
Very Low Likelihood
Kalamalka Lake
Kekuli Bay Boat Launch
Crystal Waters 2
Crystal Waters
97
Unnamed Stream
Boltres Creek
Brew Stream
Cosens Creek
Sturt Creek
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
0 375 750 1,500 2,250 3,000
Meters

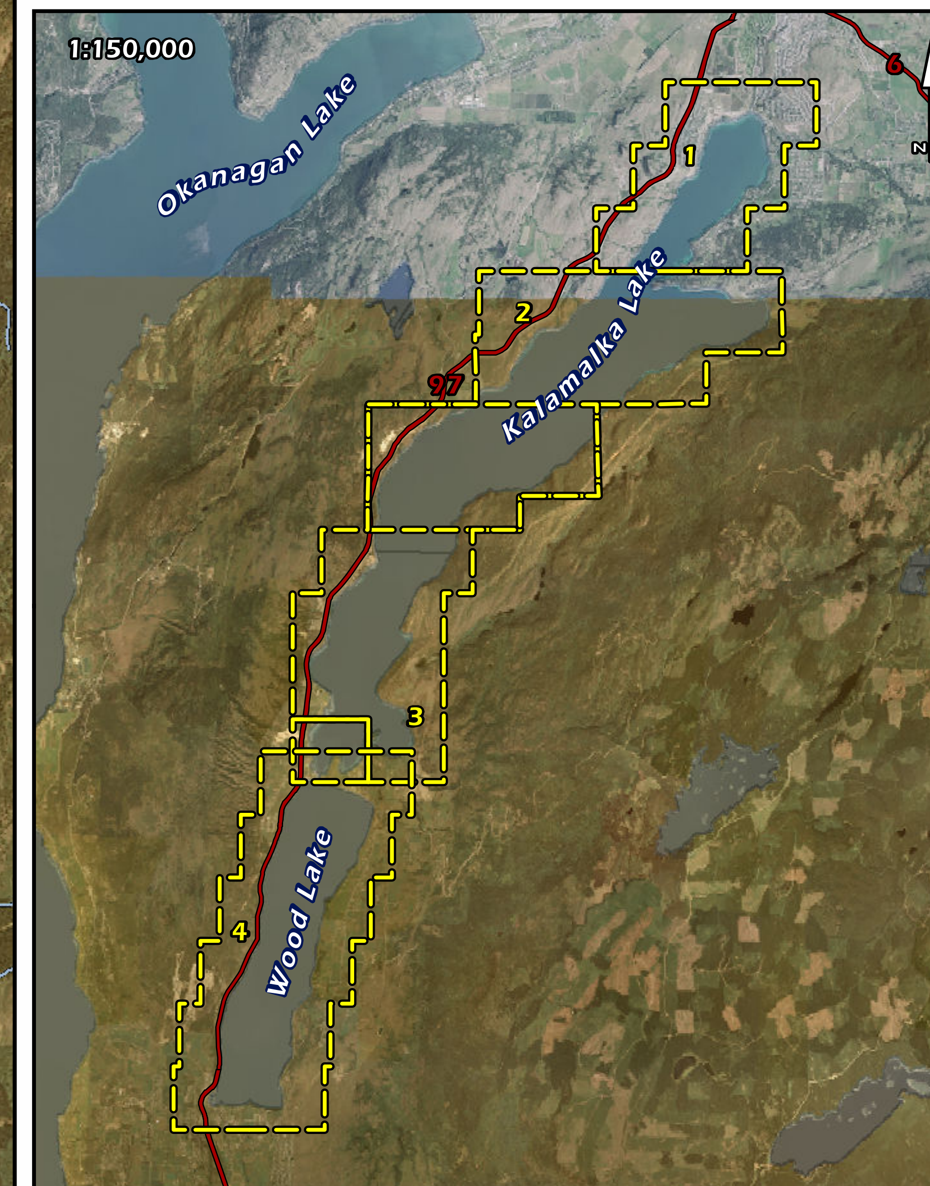
Mapsheet 3: South Kalamalka Lake



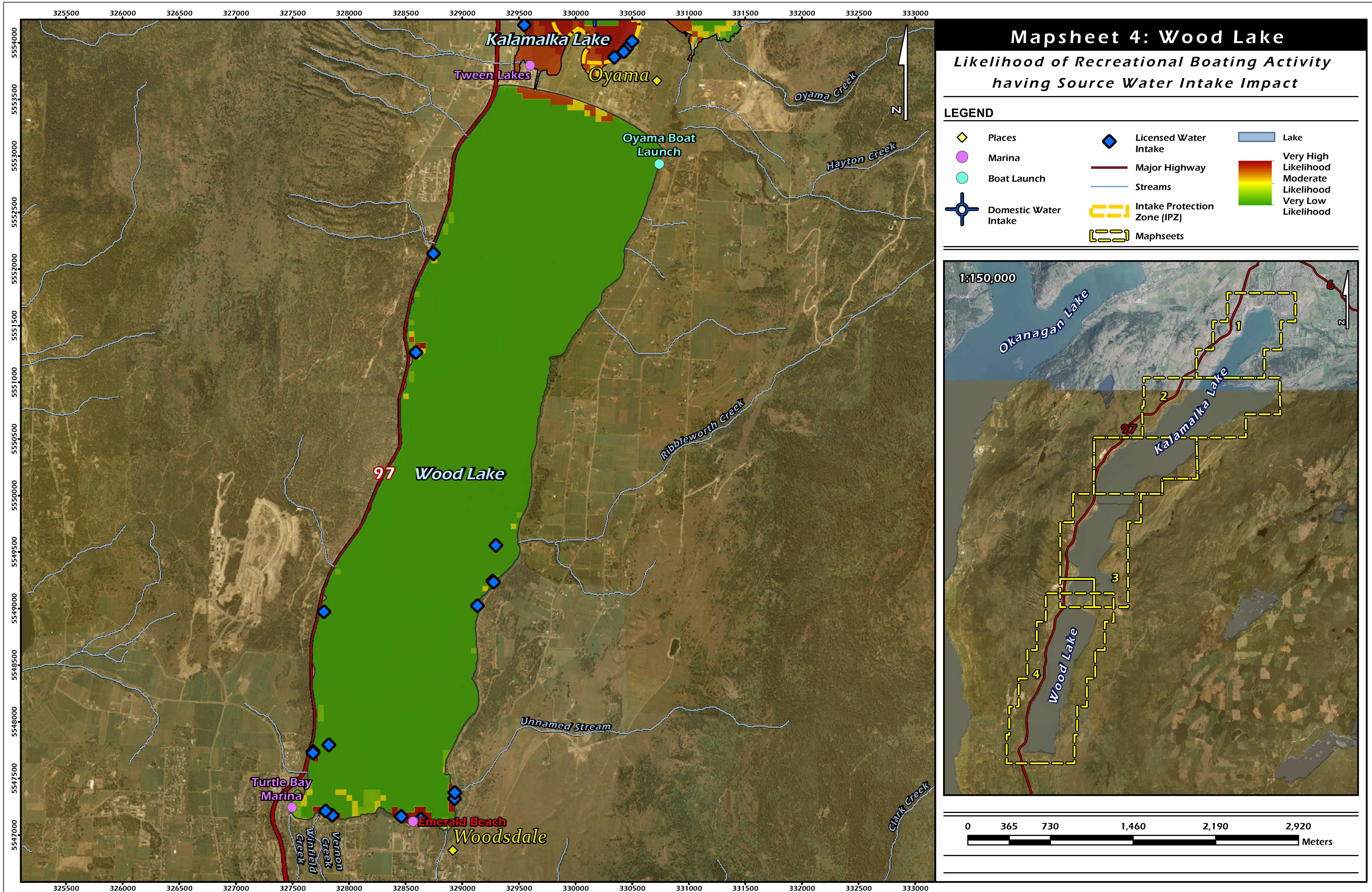
Likelihood of Recreational Boating Activity having Source Water Intake Impact

LEGEND

- Places
- Marina
- Boat Launch
- Domestic Water Intake
- Licensed Water Intake
- Major Highway
- Streams
- Intake Protection Zone (IPZ)
- Maphseets
- Lake
- Very High Likelihood
- Moderate Likelihood
- Very Low Likelihood

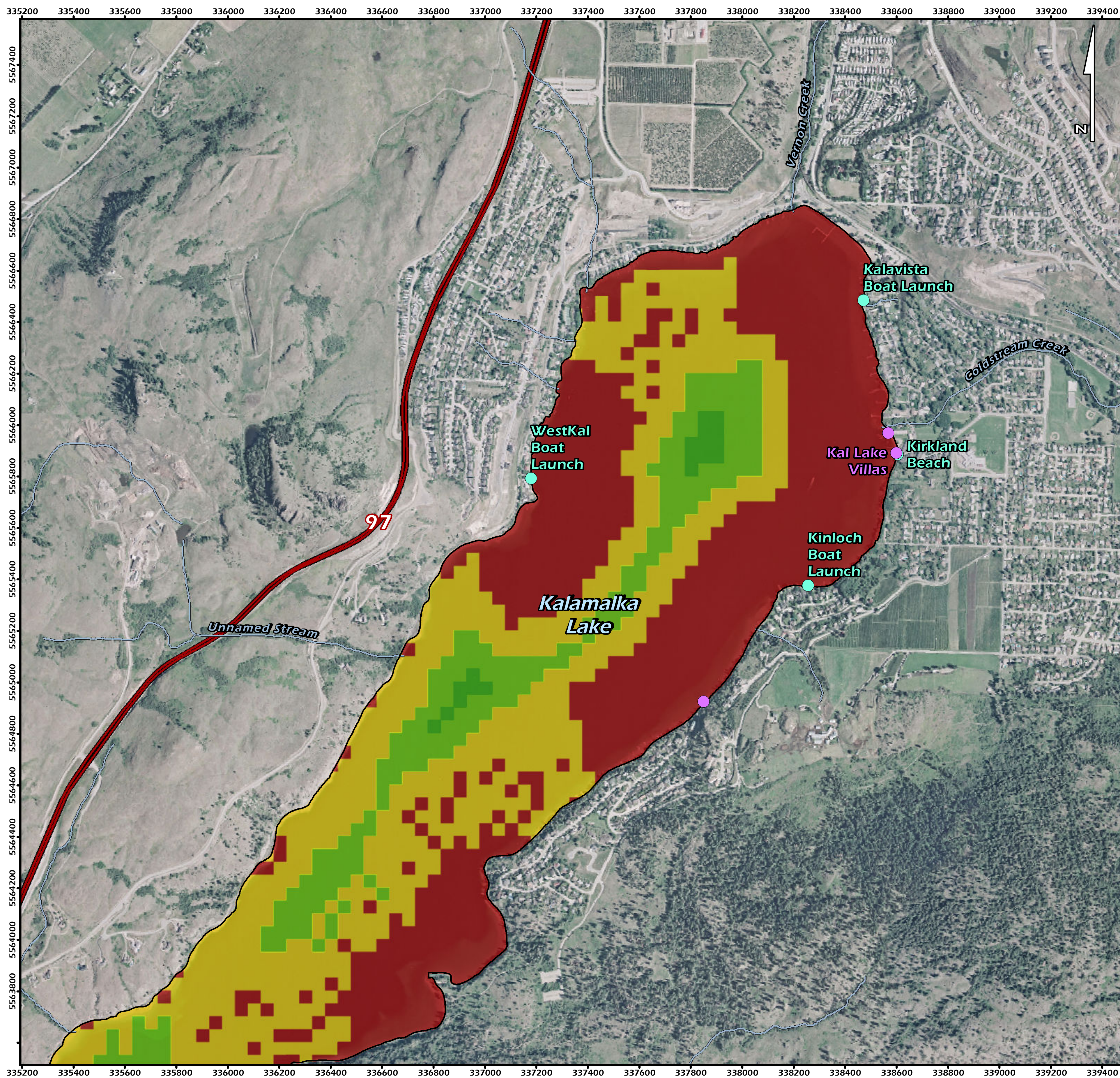


0 365 730 1,460 2,190 2,920 Meters



Mapsheet 4: Wood Lake
Likelihood of Recreational Boating Activity having Source Water Intake Impact
LEGEND
Places
Marina
Boat Launch
Domestic Water Intake
Licensed Water Intake
Major Highway
Streams
Intake Protection Zone (IPZ)
Maphseets
Lake
Very High Likelihood
Moderate Likelihood
Very Low Likelihood
1:150,000
Okanagan Lake
Kalamalka Lake
Wood Lake
97
6
1
2
3
4
0 365 730 1,460 2,190 2,920
Meters
Kalamalka Lake
Tween Lakes
Oyama
Oyama Creek
Oyama Boat Launch
Hayton Creek
Ribbleworth Creek
Wood Lake
97
Unnamed Stream
Turtle Bay Marina
Emerald Beach
Woodsdale
Winfield Creek
Vernon Creek
Clark Creek
325500 326000 326500 327000 327500 328000 328500 329000 329500 330000 330500 331000 331500 332000 332500 333000
5554000 5553500 5553000 5552500 5552000 5551500 5551000 5550500 5550000 5549500 5549000 5548500 5548000 5547500 5547000
N

Environmental Risk Maps

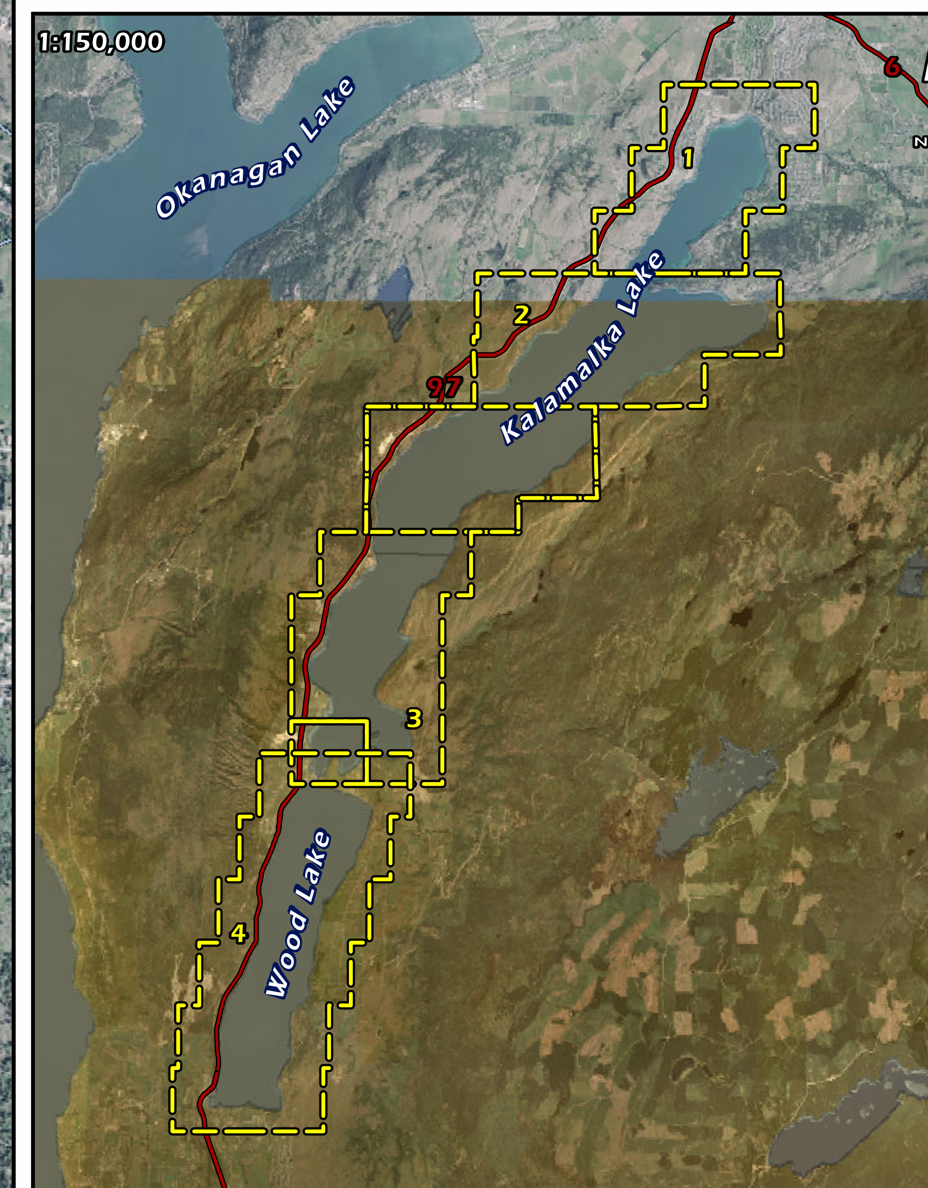


Mapsheet 1: North Kalamalka Lake

Likelihood of Recreational Boating Activity having Environmental Impact

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake
- Very High Likelihood
- Moderate Likelihood
- Very Low Likelihood



0 195 390 780 1,170 1,560 Meters

DISCLAIMER

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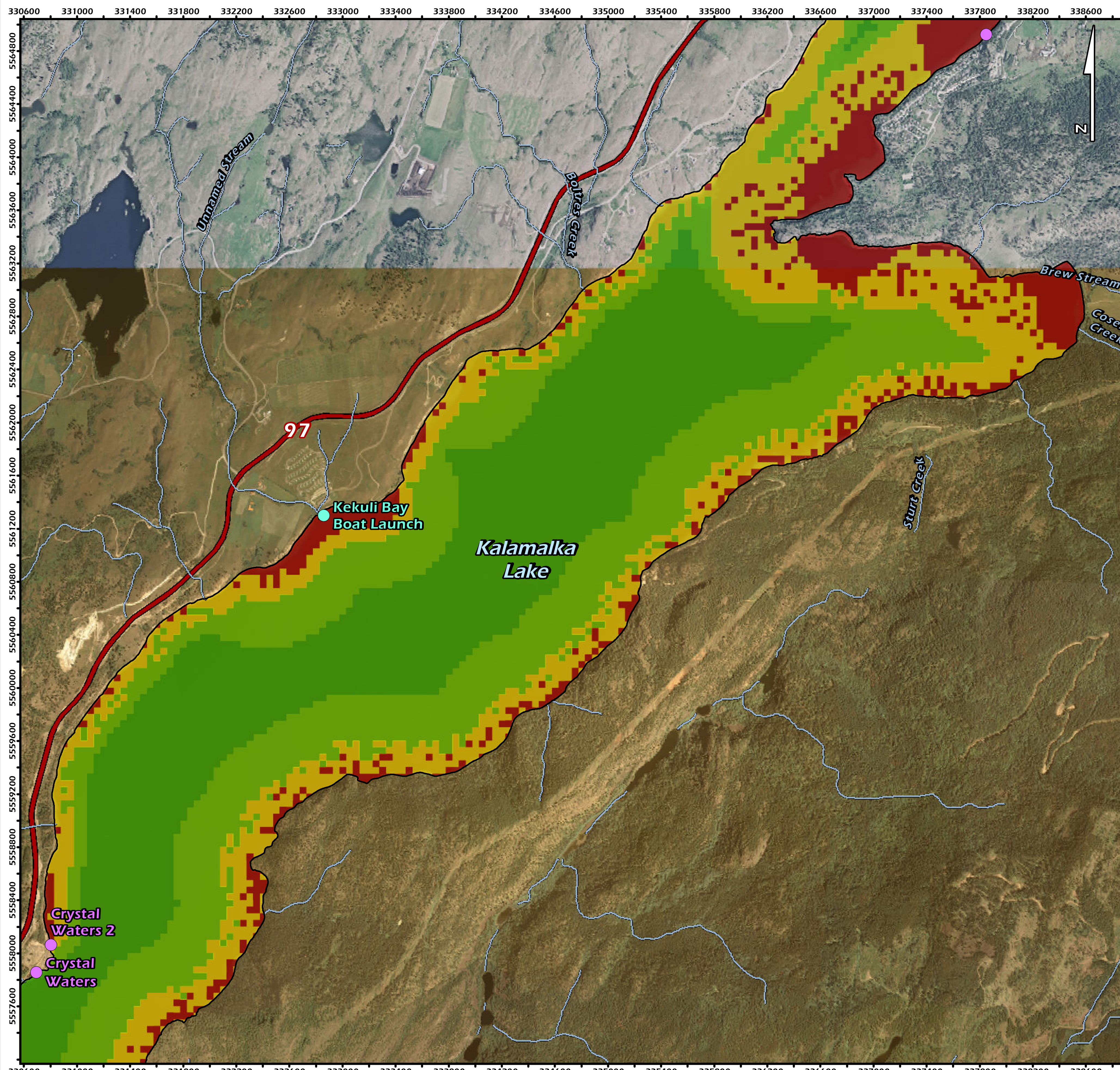
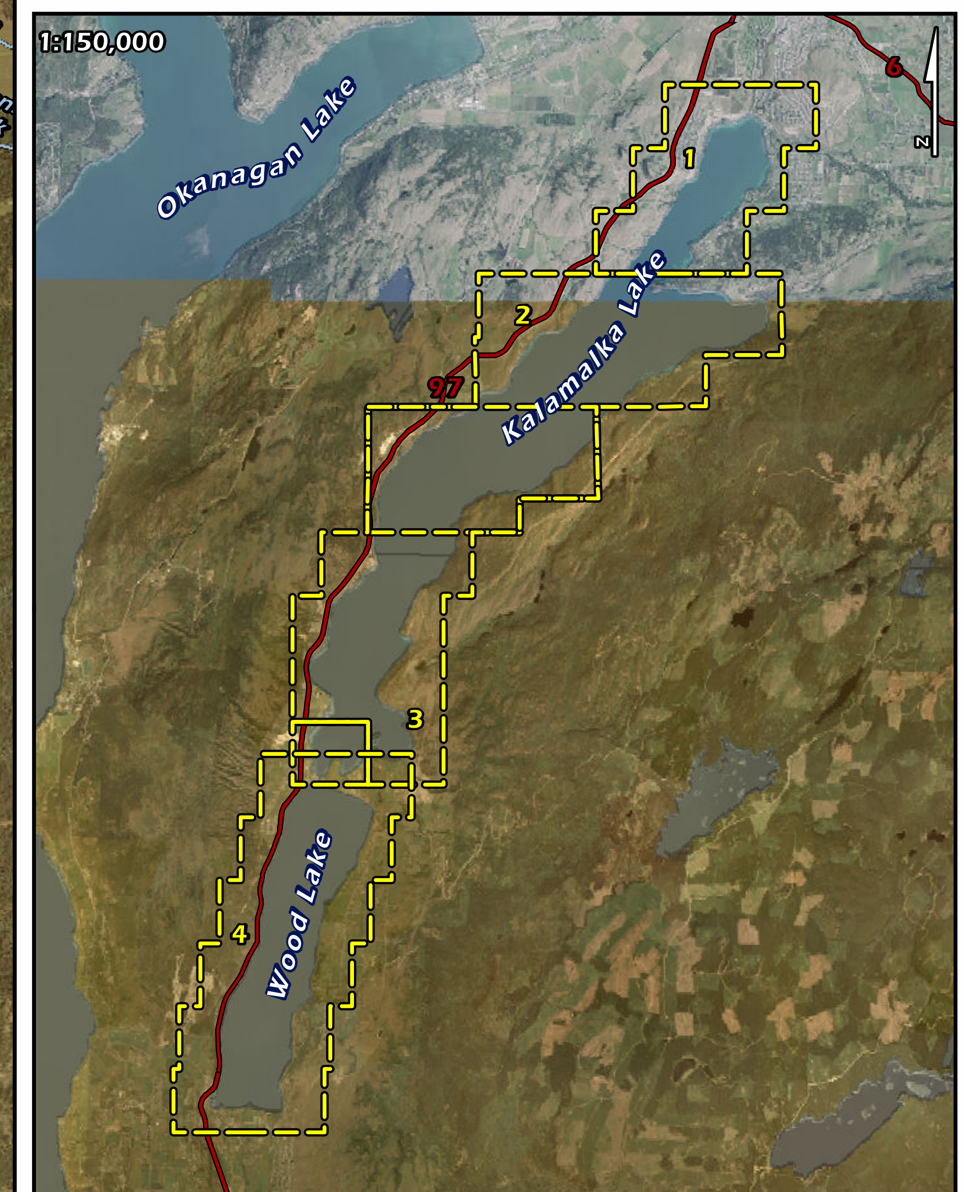
Mapsheet 2: Mid Kalamalka Lake

Likelihood of Recreational Boating Activity having Environmental Impact



LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake
- Very High Likelihood
- Moderate Likelihood
- Very Low Likelihood



0 375 750 1,500 2,250 3,000 Meters

DISCLAIMER

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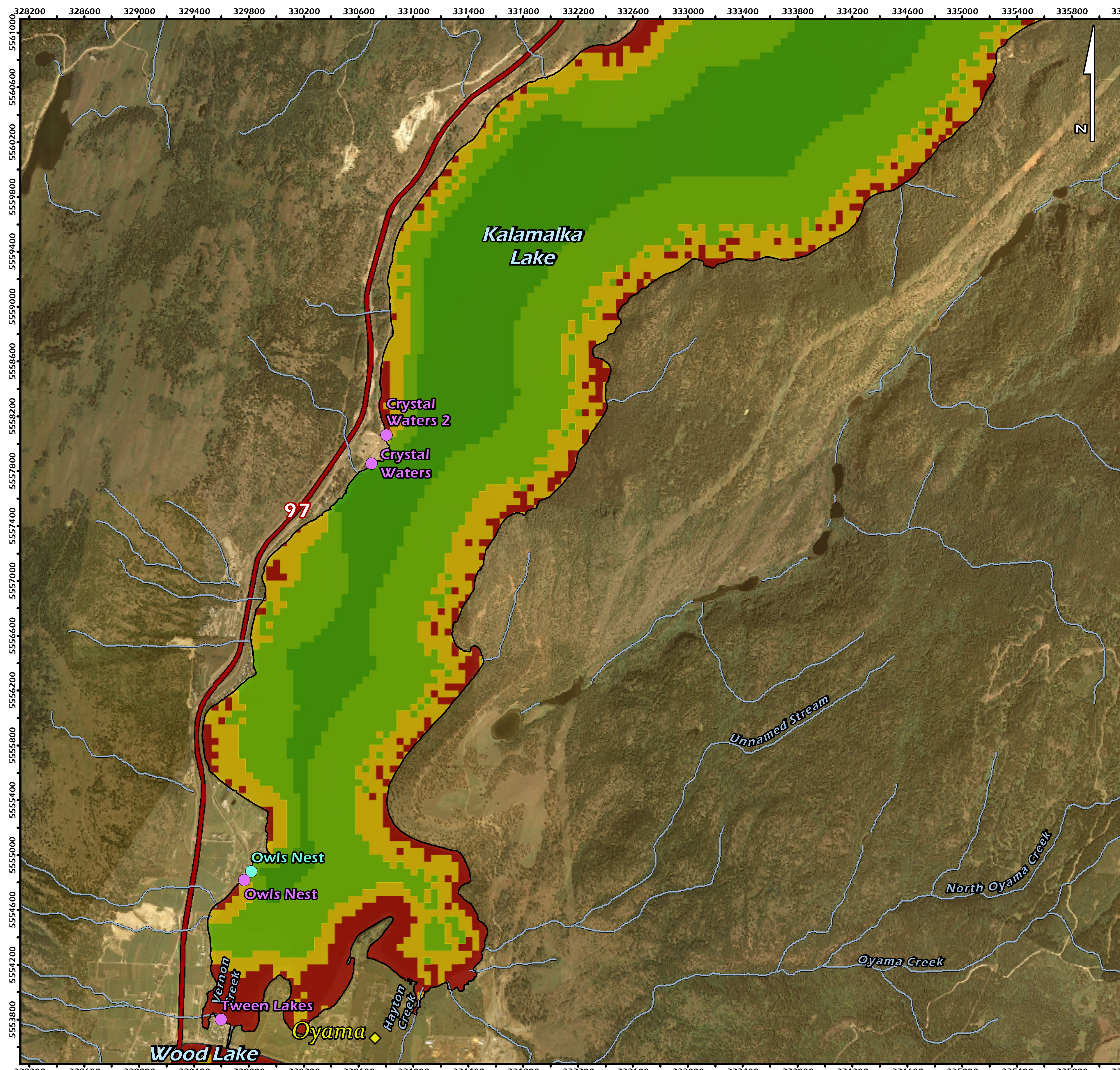
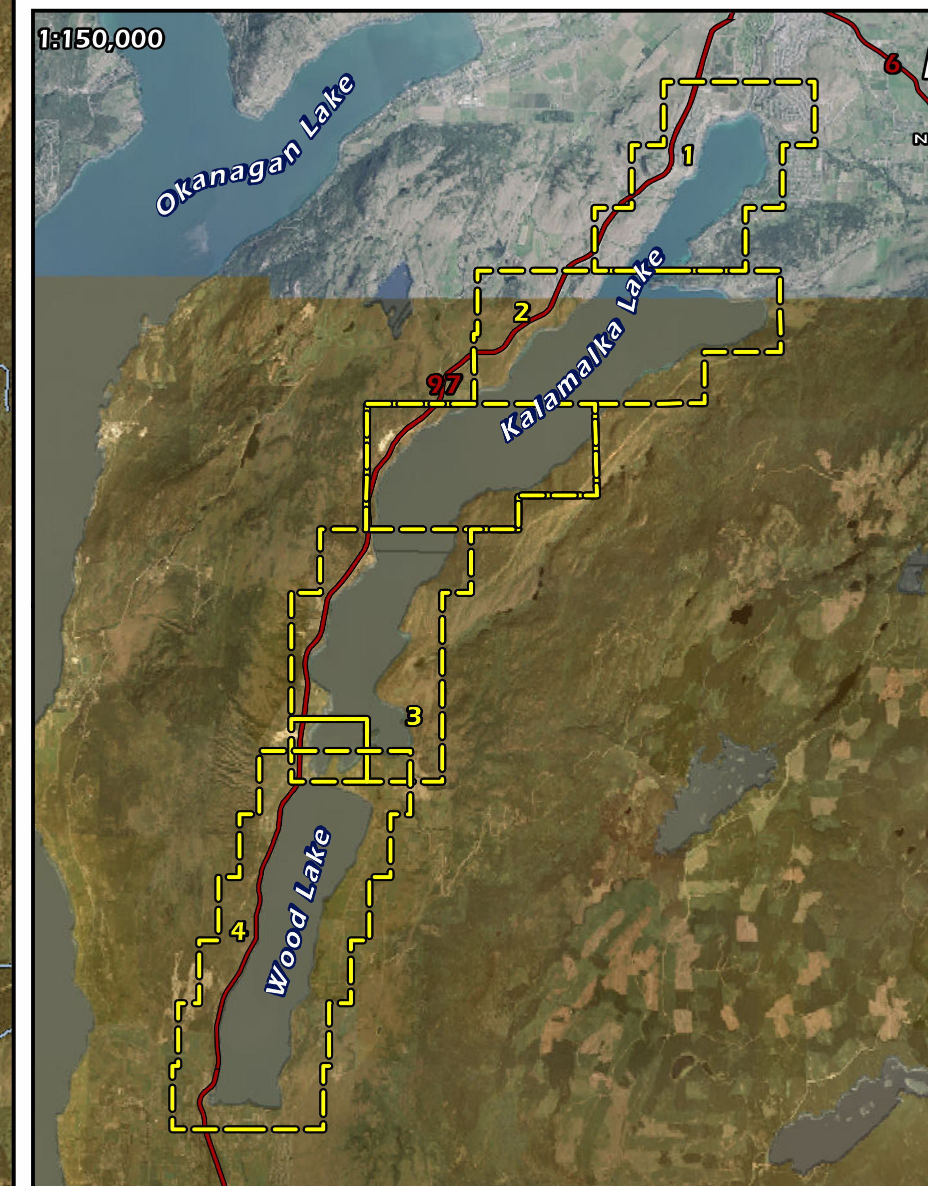


Mapsheet 3: South Kalamalka Lake

Likelihood of Recreational Boating Activity having Environmental Impact

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Maphseets
- Lake
- Very High Likelihood
- Moderate Likelihood
- Very Low Likelihood



0 365 730 1,460 2,190 2,920 Meters

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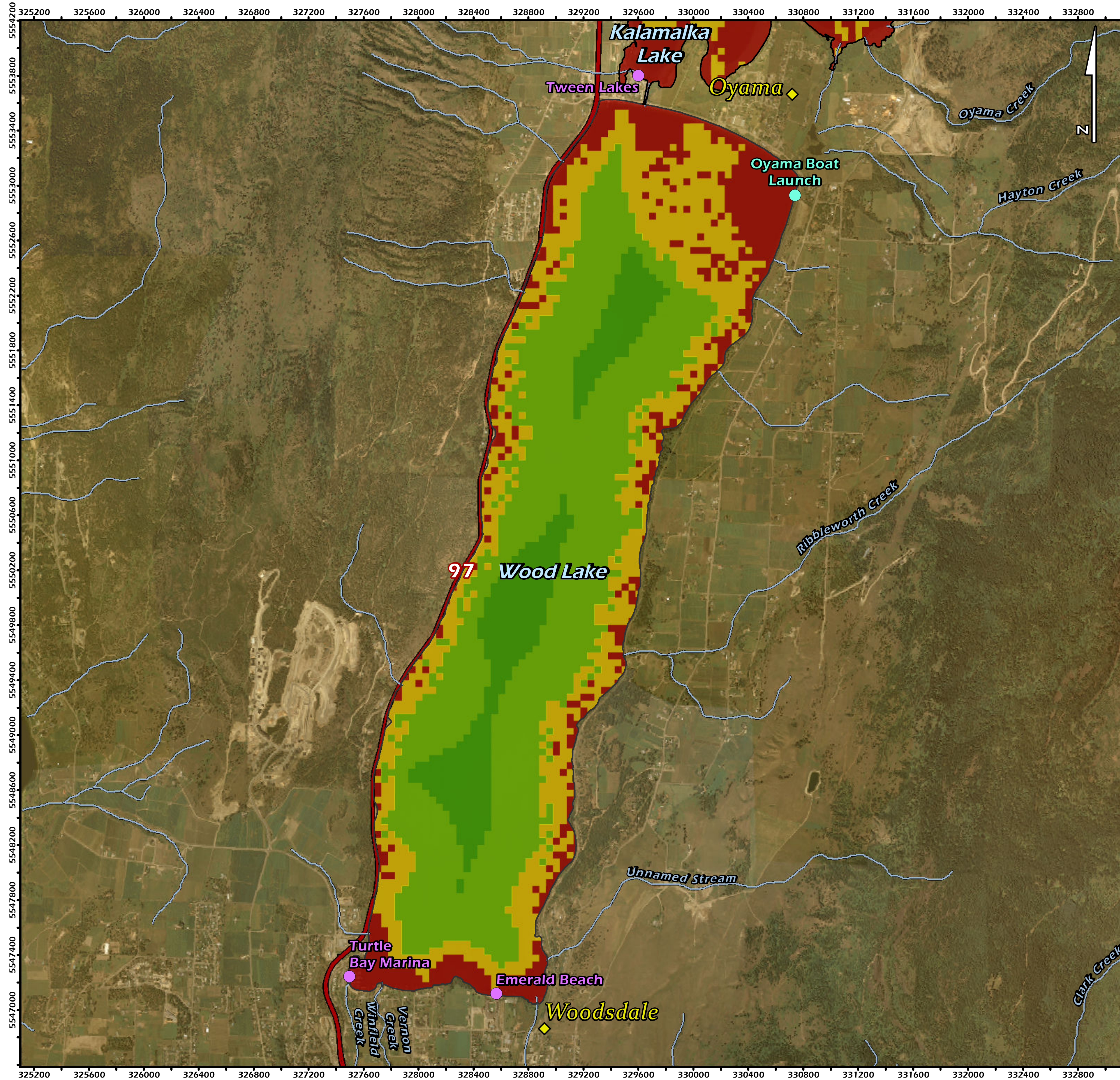
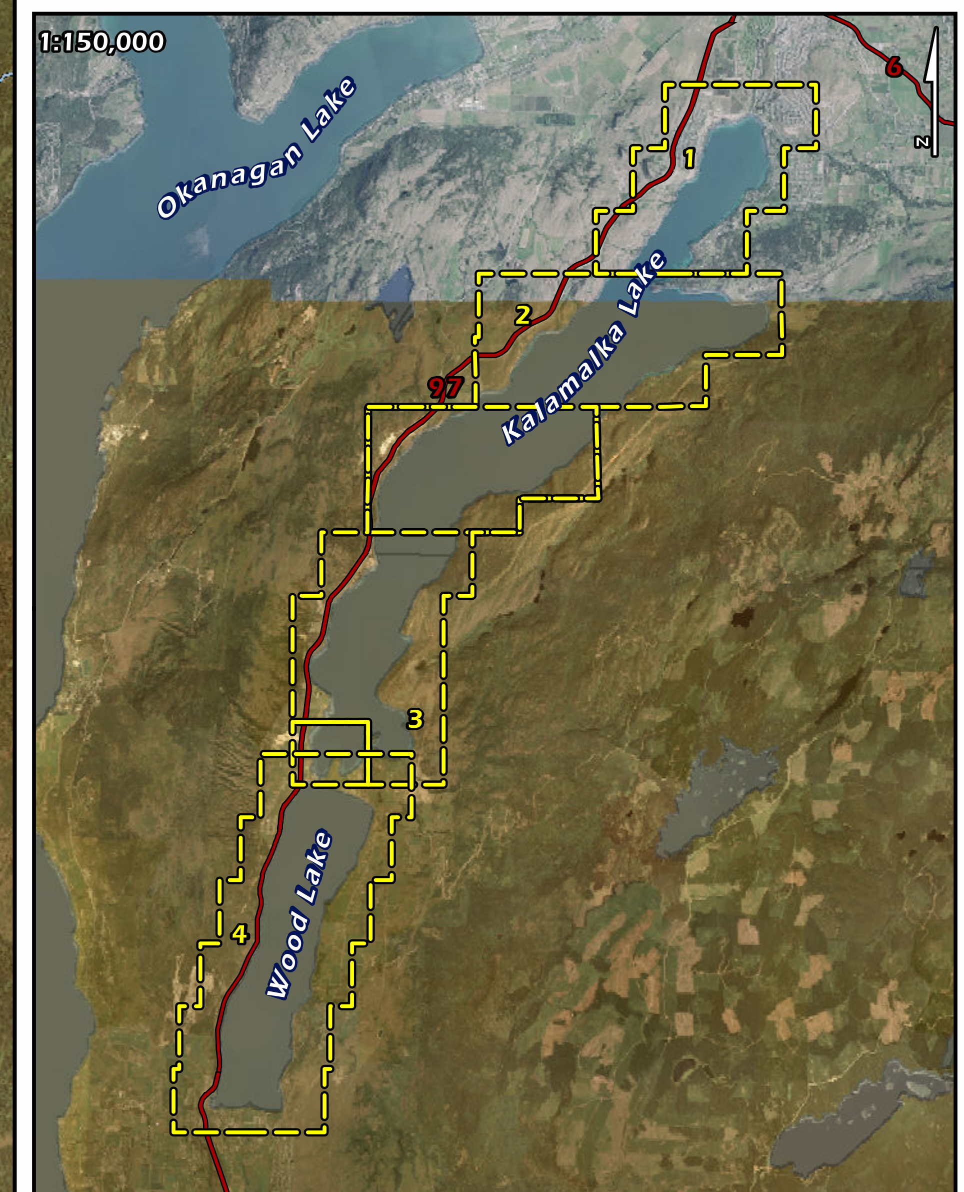


Mapsheet 4: Wood Lake

Likelihood of Recreational Boating Activity having Environmental Impact

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Mapsheets
- Lake
- Very High Likelihood
- Moderate Likelihood
- Very Low Likelihood



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER

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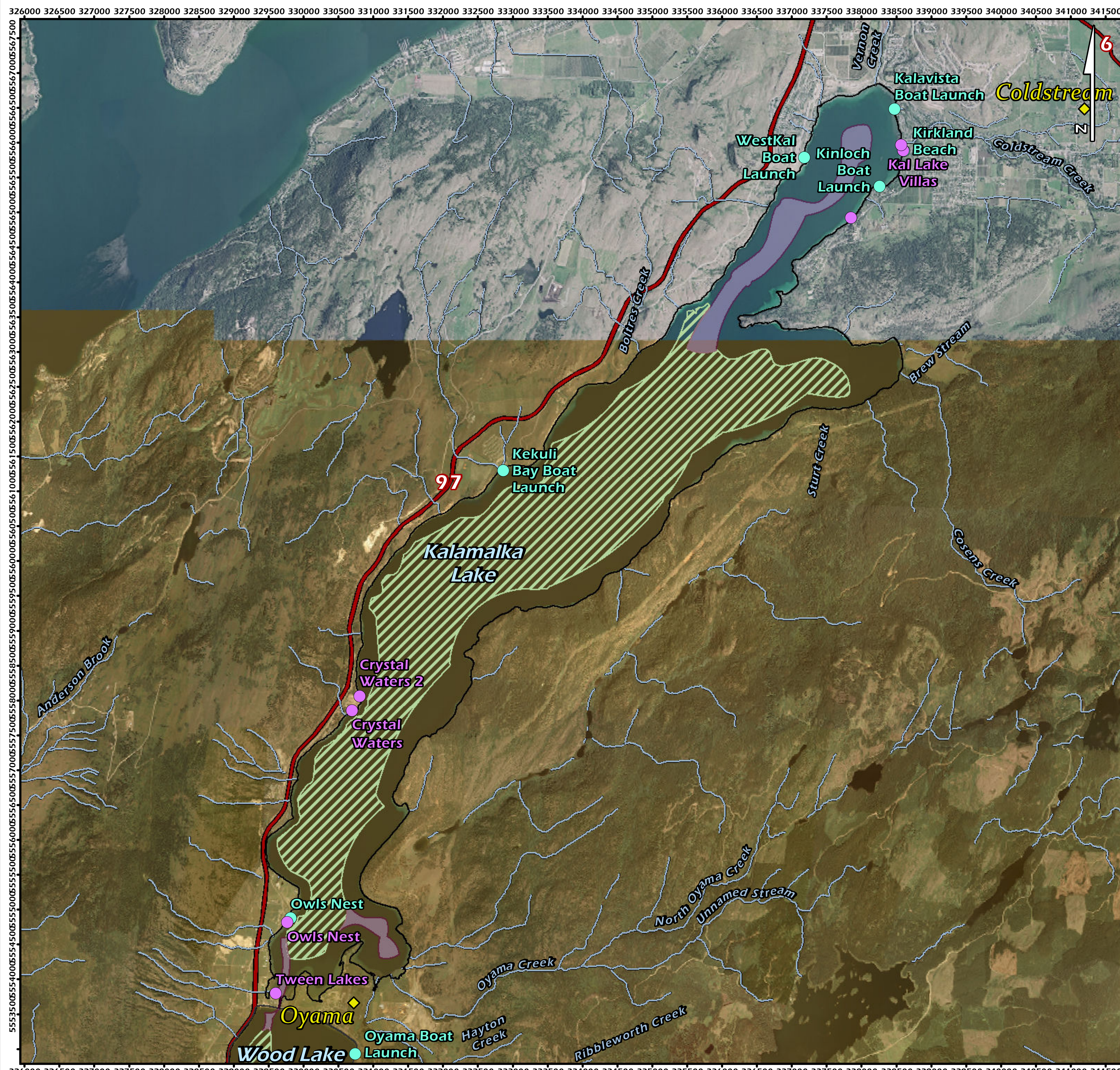
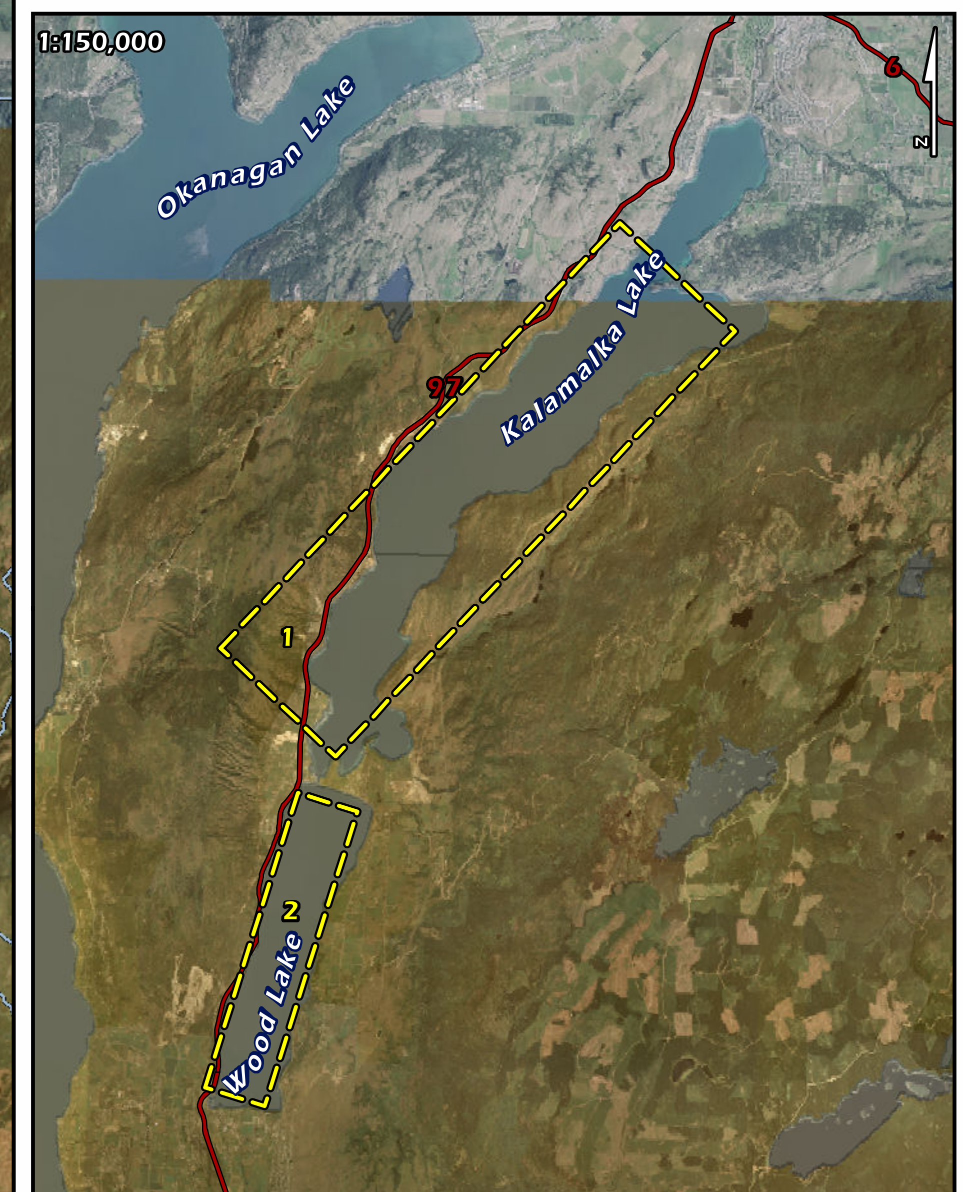


Mapsheet 1: Kalamalka Lake

Recommended Recreating Areas and Travel Corridors

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Maphseets
- Lake
- Recommended Recreation Area
- Recommended Travel Corridor



0 700 1,400 2,800 4,200 5,600 Meters

DISCLAIMER

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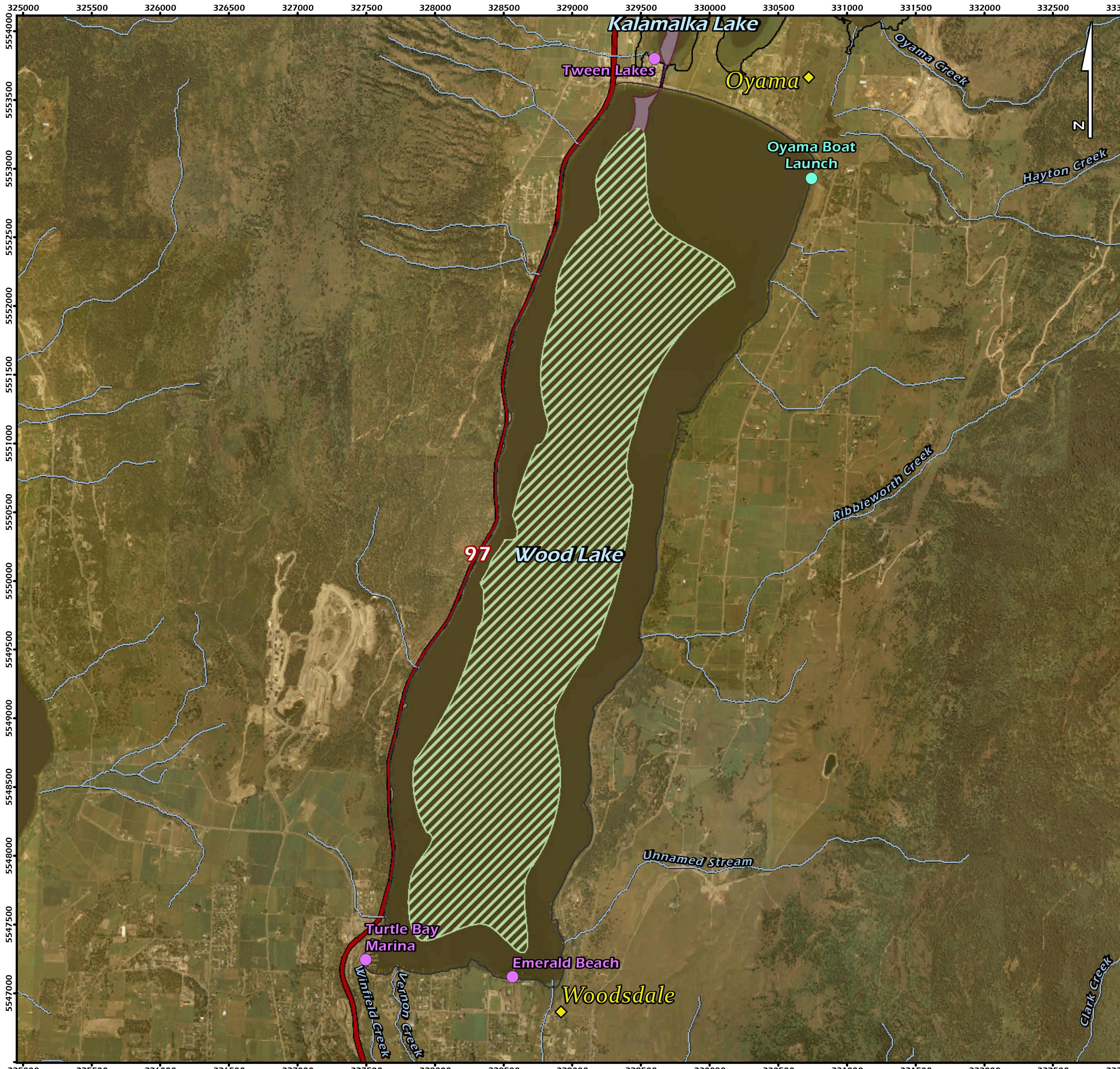
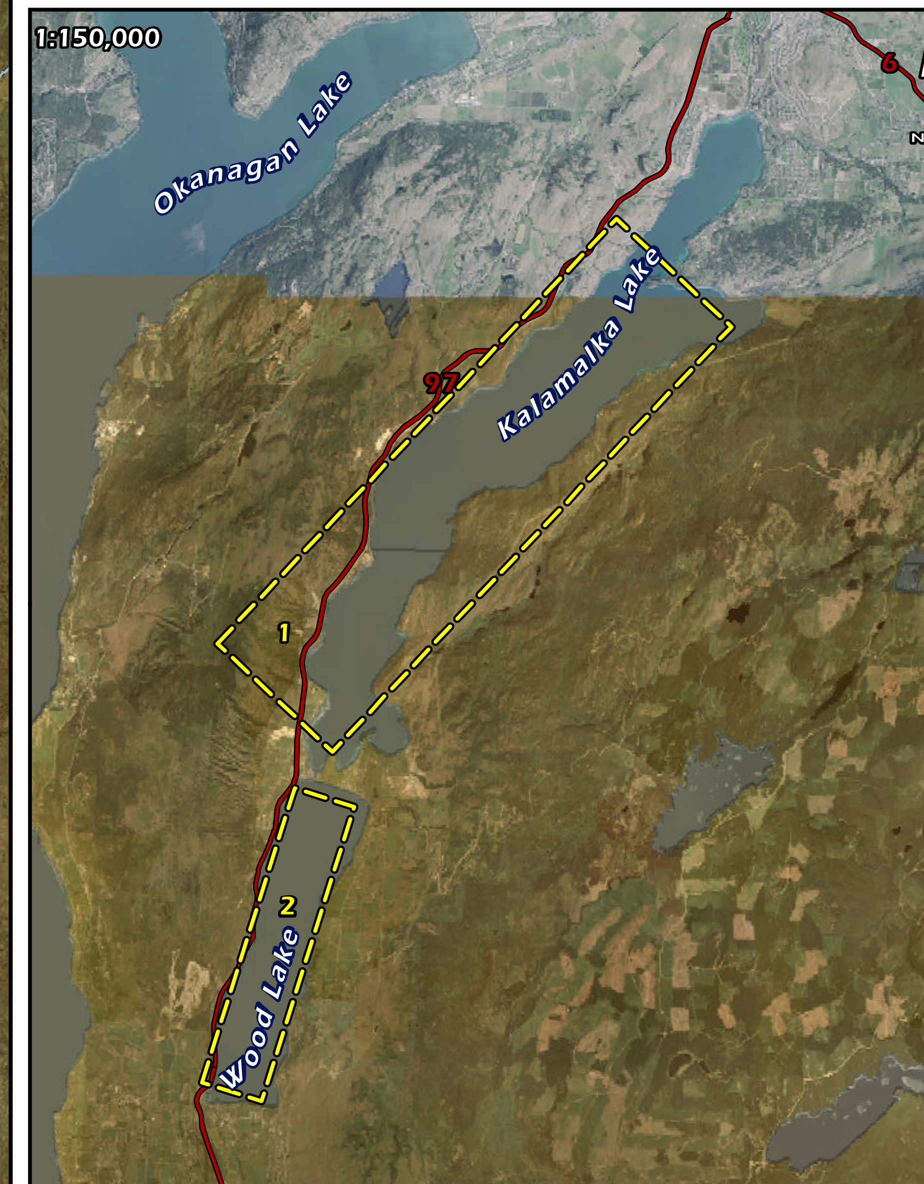


Mapsheet 2: Wood Lake

Recommended Recreating Areas and Travel Corridors

LEGEND

- Places
- Marina
- Boat Launch
- Major Highway
- Streams
- Maphseets
- Lake
- Recommended Recreation Area
- Recommended Travel Corridor



0 365 730 1,460 2,190 2,920 Meters

DISCLAIMER

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APPENDIX A

Table A1: Combined Likelihood of Depth and Distance to Source Water Intake						
		Distance to Source				
	Likelihood Level	A	B	C	D	E
Depth	A	A	B	C	D	E
	B	A	B	C	D	E
	C	N/A				
	D	N/A				
	E	E	E	E	E	E

Table A2: Combined Likelihood of Depth, Distance to Source Water Intake and Substrate						
		Combined Depth Distance Likelihood				
	Likelihood Level	A	B	C	D	E
Substrate	A	A	B	C	D	E
	B	A	B	C	D	E
	C	B	C	C	D	E
	D	D	D	D	D	E
	E	E	E	E	E	E