WASHINGTON STATE DEPARTMENT OF
Natural Resources
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Division of Geology and Earth Resources
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WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
MAP SERIES 2014-01
Lake Chaplain 7.5-minute Quadrangle
Pamphlet accompanies map

Geologic Map of the Lake Chaplain 7.5-minute Quadrangle, Snohomish County, Washington

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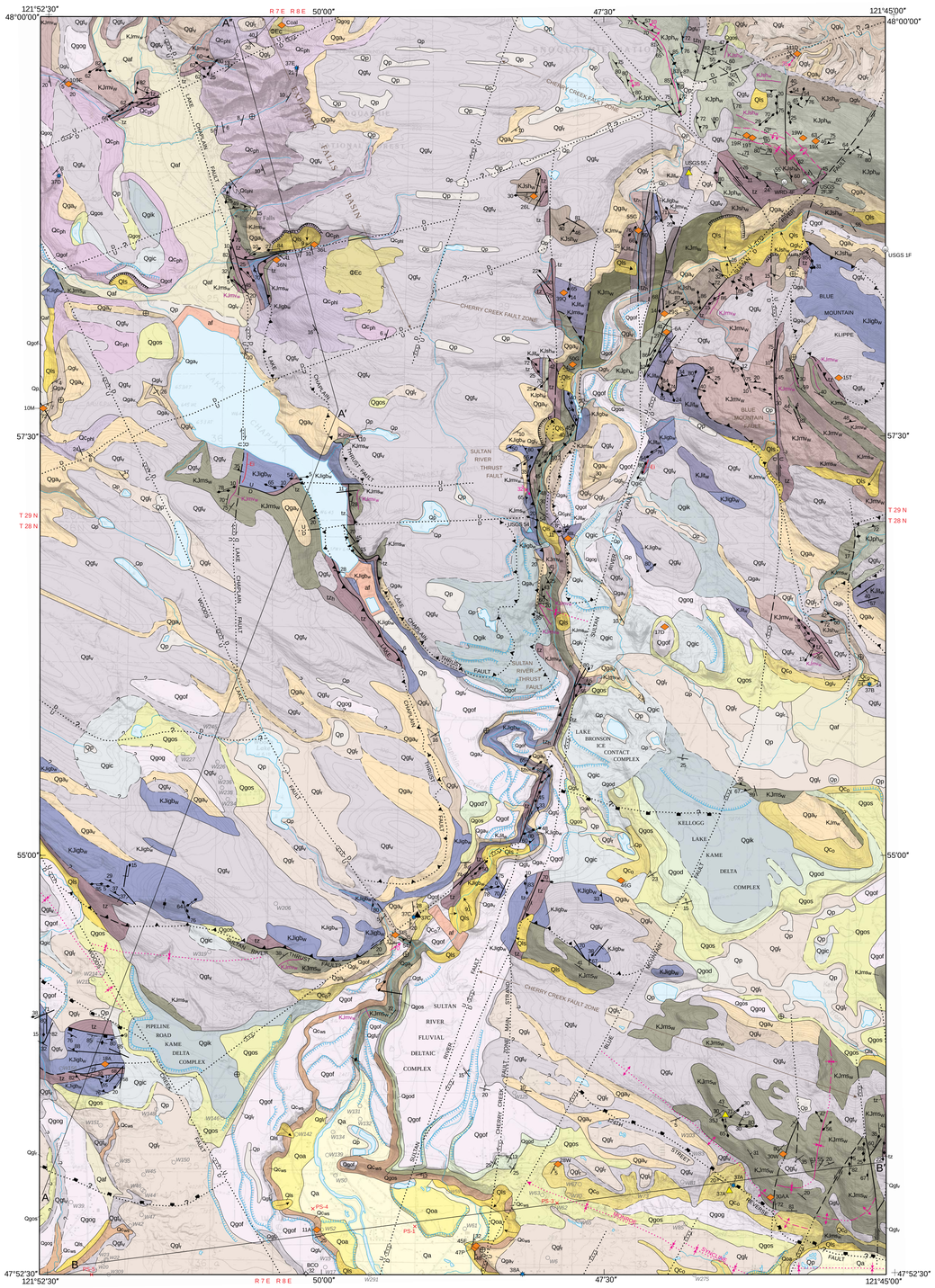
2014



MAJOR FINDINGS

- Pleistocene Skykomish River nonglacial alluvium can be correlated with deposits of the Olympia nonglacial interval, the Whidbey Formation, and nonglacial deposits older than the Hamm Creek nonglacial interval.
- The Skykomish River valley has been structurally controlled since at least the mid to late Pleistocene and perhaps longer.
- The Explorer Falls basin in the northwest map area is likely a Quaternary graben.
- The northeast-trending left-lateral Cherry Creek fault zone offsets the Monroe syncline and juxtaposes Western mélange belt rocks of contrasting metamorphic grade.
- We obtained a 74 ±1 Ma U-Pb age for the youngest detrital zircon population in Western mélange belt (WMB) feldspathic metasandstone in the southeastern part of the map area. This finding substantially reduces the age of the belt by ~22 Ma with implications for timing of local and regional mélange-belt deposition, accretion and thrusting.

DESCRIPTION OF MAP UNITS

(See the pamphlet for detailed map unit descriptions, including detailed sand provenance information in Table 1)

Quaternary Sedimentary Deposits

HOLOCENE NONGLACIAL DEPOSITS

af **Artificial fill and modified land**—Mixed earth materials including sand and gravel fill.

Qp **Peat**—Peat, muck, and organic silt and clay, locally with diatomite and thin beds of Mazama ash; loose or soft.

Qa **Alluvium**—Silt, sand, and pebble to boulder gravel; organic sediments, peat, wood debris, and detrital wood are common; loose; clasts subrounded to rounded with some subangular to angular clasts in the Sultan River alluvium; well sorted; well stratified; sand is planar bedded. See SP and LP sand provenance in Table 1 (pamphlet) and the *Geochemistry* section for detailed descriptions of the Skykomish River sands.

Qoa **Older alluvium (Holocene to latest Pleistocene)**—Silt, sand, and pebble to cobble gravel; loose; in elevated inset terraces along valley margins.

Qls **Landslide deposits (Holocene to latest Pleistocene)**—Diamicton (unsorted mixture of clay, silt, sand, gravel, and wood debris) or boulder gravel, including talus deposits and local minor sand or gravel; loose. Only large landslides are shown; absence of a mapped slide does not imply absence of hazard.

Qaf **Alluvial fan deposits (Holocene to latest Pleistocene)**—Poorly sorted debris-flow deposits and alluvial gravel; sand to boulder gravel; loose; massive to moderately stratified; poorly to moderately sorted.

PLEISTOCENE GLACIAL AND NONGLACIAL DEPOSITS

Deposits of the Vashon Stade of the Fraser Glaciation

Vashon Recessional Deposits

Qgk **Recessional glaciolacustrine (glacial lake) deposits**—Silt and clayey or sandy silt to silty sand, typically with scattered dropstones; soft; deposited in proglacial lakes.

Qgos **Outwash sand**—Sand with some interbeds of silt or gravel; loose or soft; unstratified to weakly stratified to plane bedded, laminated, and locally crossbedded.

Qgod **Deltaic outwash and kame deltas**—Sandy cobble gravel, gravel, pebbly sand, and minor sand; loose; moderately to well sorted; thin to very thickly bedded; well stratified with conspicuous high-amplitude foreset beds in this unit and Qgik, particularly in the Kellogg Lake and Pipeline Road kame delta complexes and the Sultan River fluvial-deltaic complex.

Qgof **Fluvial outwash deposits**—Boulder and cobble gravel, gravel, and pebbly sand, with interbeds of sand and silt; loose; moderately to well stratified; beds subhorizontal and locally crossbedded with rip-up clasts common.

Qgic **Ice-contact deposits**—Boulder and cobble gravel, gravel, silty pebble gravel, sand, and pebbly sand and silt, locally with minor diamicton; loose; moderately stratified and medium to very thickly bedded; abrupt grain-size changes common. Locally divided into:

Qgik **Ice-contact kames**—Boulder and cobble gravel, gravel, sand, and pebbly sand, with rare lenses of diamicton; loose; crossbedded, with localized oversteepened or slumped strata; cut-and-fill structures and rip-up clasts of till or silt common.

Qgog **Outwash gravel deposits, undivided**—Poorly exposed bouldery cobble to pebble gravel and pebbly sand; loose; massive to crudely bedded; largely ice-contact deposits; may include any of the gravelly Vashon recessional facies.

Vashon Advance Proglacial and Subglacial Deposits

Qgtv **Lodgment till**—Diamicton (unsorted mixture of clay, silt, sand, and gravel); dense; matrix-supported; accreted at the base of the Vashon ice; typically displays a friable shear fabric.

Qgav **Advance outwash deposits**—Sandy gravel, pebble gravel, cobble gravel, and sand, with local silt interbeds; dense; well sorted and stratified; thinly to thickly bedded; deltaic and bar foreset beds, cut-and-fill structures, and silt rip-up clasts common.

Qglv **Advance glaciolacustrine deposits**—Clayey silt, silt, pebbly silt, and diamicton; locally contains very thin to thick beds of sand, scattered dropstones, and iceberg melt-out or flow till; stiff or dense; stratification and sorting vary; massive to thinly bedded, laminated, or varved with ice-shear folds locally noted.

Pre-Fraser Glacial and Nonglacial Deposits

Qcp **Deposits of the Olympia nonglacial interval, ancient Skykomish River facies**—Silt to sand and organic silt with some clay; minor peat, charcoal, disseminated detrital organic matter, and gravel beds; sand is typically yellow-brown to gray and weathers orange-gray, light yellow-brown, or gray; dense; well stratified; laminated to very thickly bedded with graded beds, trough-and-ripple crossbedding, and liquefaction features common.

Qcws **Whidbey Formation, ancient Skykomish River facies**—Sand, silt, and silty sand with minor pebbly sand, clay, gravel, organic sediment, including peat, and a few lenses of cobble gravel; sand is yellow-gray or brown and weathers to a distinctive orange-gray; dense or hard; well sorted and stratified.

Qcph **Pre-Hamm Creek continental nonglacial deposits, ancient Pilchuck or Skykomish River facies**—Boulder to cobble gravel, pebbly gravel, gravelly sand, and sand with minor silt; sand is typically yellow-brown to brown, oxidized, and strongly weathered, with conspicuous mica; thin to very thickly bedded and typically well stratified; may contain graded beds, crossbedding, charcoal, disseminated organic matter, and logs.

Qcphl **Pre-Hamm Creek continental deposits, locally derived facies**—Pebbly sand, sand, and pebble gravel, with local minor gravel and rare silt; may locally contain peat or organic sediments; sediments have a distinct local Western mélange belt provenance.

Qgrpf **Pre-Fraser glacial and nonglacial deposits, undivided (Pleistocene to Pliocene?)(cross sections only)**—Dense to very dense gravel, boulder gravel, sand, silt, clay, and diamicton; may locally contain peat or organic sediments.

Tertiary Sedimentary Rocks

Ec **Sedimentary rocks, undivided (Oligocene to Eocene)**—Poorly exposed feldspathic sandstone with lesser conglomerate, siltstone, and coal preserved in the Explorer Falls basin in the northwestern part of the map.

Mesozoic Low- to Medium-Grade Metamorphic Rocks (Prehnite–Pumpellyite to Greenschist Facies)

KJmw **Western mélange belt of Tabor and others (1993), undivided (Cretaceous to Jurassic)**—Contains meta-argillite, metasandstone, greenstone, metagabbro, metachert, metadiabase, metatonalite, slate, phyllite, marble with lesser metaquartz diorite, hornblendite, and (banded) amphibolite, with rare ultramafite observed regionally. Locally divided into:

KJmvw **Metavolcanic rocks**—Low-grade greenstone derived from metamorphosed andesitic to basaltic tuff, basaltic andesite to dacitic volcanic flows (55–70% SiO_2), and rare volcanic breccia.

KJsh **Greenschist**—Medium-grade foliated metavolcanic rocks derived from metamorphosed basaltic to dacitic tuff (≦77% SiO_2) and flows (49–70% SiO_2); locally with interbeds of volcanic-clast-rich foliated metasandstone or phyllite.

KJmsw **Metasedimentary rocks**—Low-grade marine feldspathic to feldspatholithic subquartzose metasandstone, silty metasandstone, meta-argillite, metatuff, and minor metachert, marble, and metaconglomerate with metatuff interbeds; well to moderately sorted.

KJphw **Phyllite**—Medium-grade phyllite, phyllitic metasandstone, meta-argillite, and slate, locally with foliated metatuff interbeds; typically moderately to well-stratified sequences of phyllite and foliated metasandstone with well-developed phyllitic to semi-schistose foliation.

KJgbw **Metagabbro**—Medium-grade metagabbro with minor trondhjemite; flaser gneissic fabric with rare metaquartz diorite; medium to coarse grained; generally massive to slightly foliated; locally schistose or gneissose.

KJdw **Metatrondhjemite**—Medium-grade metatrondhjemite (~74% SiO_2) with minor metatonalite, gneiss, and metagabbro; equigranular, medium to coarse grained with cataclastic to (proto)mylonitic zones near thrust faults.

Holocene to Tertiary Tectonic Zones

tz **Tectonic zone**—Cataclasite, fault breccia, clay-rich fault gouge, protomylonite, or moderately to strongly slickensided, fractured, and veined rocks in fault zones; various colors, mottled, and commonly altered. Unit tzh represents mappable zones of hydrothermal alteration, typically along tectonic zones; principally propylitic alteration mineral assemblages, but locally may include higher grades of hydrothermal alteration.

GEOLOGIC SYMBOLS

- Contact—Solid where location accurate; long-dashed where approximately located; short-dashed where inferred; queried where identity or existence questionable
- Fault, unknown offset—Solid where location accurate; long-dashed where approximately located; dotted where concealed
- Thrust fault—Solid where location accurate; long-dashed where approximately located; short-dashed where inferred; dotted where concealed; queried where identity or existence questionable; triangles on upper plate
- Reverse fault—Solid where location accurate; dotted where concealed; queried where identity or existence questionable; rectangles on upthrown block
- High-angle dip-slip fault—Solid where location accurate; long-dashed where approximately located; dotted where concealed; queried where identity or existence questionable; U, upthrown block; D, downthrown block
- Right-lateral strike-slip fault—Long-dashed where approximately located; dotted where concealed; arrows show relative movement
- Left-lateral strike-slip fault—Solid where location accurate; long dash where approximately located; short dash where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative movement
- High-angle right-lateral oblique-slip fault—Solid where location accurate; dash where inferred; dotted where concealed; queried where identity or existence questionable; arrows show relative horizontal motion; U, upthrown block; D, downthrown block
- High-angle left-lateral oblique-slip fault—Solid where location accurate; long dash where approximately located; dotted where concealed; arrows show relative horizontal motion; U, upthrown block; D, downthrown block
- Anticline—Solid where accurately located; long dash where approximately located; dotted where concealed
- Syncline—Solid where accurately located; long dash where approximately located; short dash where inferred; dotted where concealed; arrow shows plunge direction
- Overturned anticline—Location approximate; beds on one limb are overturned; arrows show dip direction of limbs
- Geologic unit too thin to show as a polygon—Identity and existence certain; location accurate; unit KJmvw or KJshw
- Basalt or andesite dike (unit Ei, Eocene intrusive)—Identity and existence certain; location accurate
- Fluvial terrace scarp—Identity and existence certain; location accurate; hachures point downscarp
- Landslide scarp—Identity and existence certain; location accurate; hachures point down slope
- B—B′ Cross section line
- Direction of downslope movement of landslide
- 60 Minor inclined fault—showing strike and dip
- Minor vertical or near-vertical fault—showing strike
- Horizontal bedding
- Vertical bedding—showing strike
- 60 Inclined bedding—showing strike and dip
- 10 Inclined bedding in unconsolidated sedimentary deposits—showing strike and dip
- 23 Inclined foreset bedding in unconsolidated sedimentary deposits—showing strike and dip
- 80 Overturned bedding—showing strike and dip
- 52 Inclined metamorphic or tectonic cleavage—showing strike and dip
- Vertical metamorphic or tectonic cleavage—showing strike
- 67 Minor inclined joint—showing strike and dip
- Minor vertical or near-vertical joint—showing strike
- 32 Inclined crenulation lineation—showing bearing and plunge
- 35 Inclined fold hinge of generic (type unspecified) minor fold—showing bearing and plunge
- 25 Inclined slickenline, groove, or striation on fault surface—showing bearing and plunge
- 20 Inclined slickenside—showing strike and dip
- Vertical slickenside—showing strike
- 71 Inclined, aligned stretched-object lineation—showing bearing and plunge
- 70 Inclined mylonitic foliation—showing strike and dip
- USGS 1F Geochronology sample, fossil
- USGS 54 Geochronology sample, K-Ar, potassium-argon
- USGS 55 Geochronology sample, U-Pb, uranium-lead
- 37C Geochronology sample, ^{14}C, carbon-14
- 37D Geochronology sample, optically stimulated luminescence
- W62 Water well
- BCO-32 Drill hole or boring
- 26L Significant site
- PS-5 Geophysical data collection locality

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GEOPHYSICAL DATA AND INTERPRETATIONS

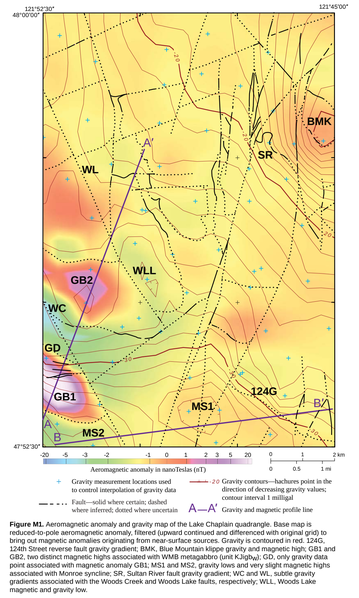
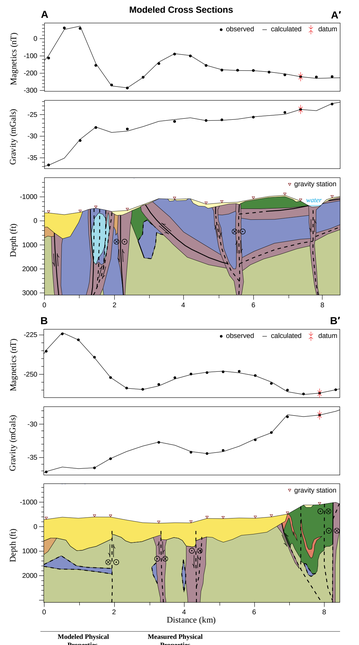


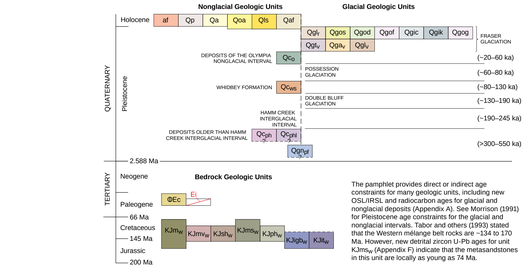
Figure M1. Aeromagnetic anomaly and gravity map of the Lake Chaplain quadrangle. Base map is reduced-to-pole aeromagnetic anomaly, filtered (upward continued and differenced with original grid) to bring out magnetic anomalies originating from near-surface sources. Gravity is contoured in red. 124G, 124th Street reverse fault gravity gradient; BMK, Blue Mountain klippe gravity and magnetic high; GB1 and GB2, two distinct magnetic highs associated with WMB metagabbro (unit $KJgb_w$); GD, only gravity data point associated with magnetic anomaly GB1; MS1 and MS2, gravity lows and very slight magnetic highs associated with Monroe syncline; SR, Sultan River fault gravity gradient; WC and WL, subtle gravity gradients associated with the Woods Creek and Woods Lake faults, respectively; WLL, Woods Lake magnetic and gravity low.

Modeled Cross Sections



Modeled Physical Properties		Measured Physical Properties		
Density contrast (kg/m^3)	Susceptibility	Saturated bulk density (kg/m^3)	Susceptibility (hand and outcrop sample)	Geologic units
		Quaternary deposits		
$\Delta\rho$ = -660	χ = 2.6			undifferentiated Quaternary deposits
$\Delta\rho$ = -620	χ = 10			Snoqualmie or Skykomish River basin provenance, unit SP
		Tertiary rocks		
$\Delta\rho$ = -400	χ = 1.1			sedimentary, unit Ec
		Western mélange belt		
$\Delta\rho$ = 130	χ = 0.74	ρ_b = 2720 ±30	χ = 0.28 ±0.11	phyllite and slate, unit $KJph_w$
$\Delta\rho$ = 50	χ = 0.28	ρ_b = 2840 ±130	χ = 21.63 ±4.55	metagabbro, unit $KJgb_w$
$\Delta\rho$ = 170	χ = 50	ρ_b = 2650 ±30	χ = 0.32 ±0.06	metasedimentary, unit $KJms_w$
$\Delta\rho$ = -20 to -50	χ = 0	ρ_b = 2800 ±40	χ = 2.03 ±0.74	metavolcanic, unit $KJmv_w$
$\Delta\rho$ = 50	χ = 0.78	ρ_b = 2720	χ = 0.78	unit $KJms_w$ excluding metagabbro
		ρ_b = 2730	χ = 3.94	unit $KJms_w$ including metagabbro
		Tectonic zones		
$\Delta\rho$ = -70 to 50	χ = 0 to 20		χ = 0.44	undifferentiated cataclasite of units KJm_w and $KJgb_w$ (units tz and tz_h)

CORRELATION OF MAP UNITS



The pamphlet provides direct or indirect age constraints for many geologic units, including new OSL/IRSL and radiocarbon ages for glacial and nonglacial deposits (Appendix A). See Morrison (1991) for Pleistocene age constraints for the glacial and nonglacial intervals. Tabor and others (1993) stated that the Western mélange belt rocks are ~134 to 170 Ma. However, new detrital zircon U-Pb ages for unit $KJmv_w$ (Appendix F) indicate that the metasandstones in this unit are locally as young as 74 Ma.

Lithologic Cross Sections A and B. For analyses of subsurface conditions, 344 well, 32 geotechnical boring, and 24 test pit stratigraphic logs were obtained from various public and private institutions. We show only the highest quality well and boring data near the cross sections. We show composite information where wells and borings are closely spaced and (or) where subsurface geologic conditions are stratigraphically consistent over a short distance. On Cross Section B–B′, additional constraints on the depth to bedrock are derived from passive seismic analyses at sites PS-1, PS-3, and PS-5. Although other solutions are possible, our geophysical model of the map area is consistent with the postulated stratigraphic arrangement (see Figs. M1 and M2, this plate). Appendix B (pamphlet) provides information on earthquake hypocenters near the cross sections. The relationship between the Lake Chaplain and Sultan River thrusts and the Lake Chaplain nappe is illustrated on Figure 15 in the pamphlet.

CROSS SECTION EXPLANTION

- Surficial geologic units too thin to show as polygons at the scale of the cross sections. Black tick marks separate units.
- Arrows show relative fault movement in the plane of the cross section
- Arrow point shows fault movement toward the viewer; arrow feathers show fault movement away from the viewer
- PS-5 Geophysical depth-to-bedrock constraint
- Water well or boring; water well labels begin with W; boring labels begin with B

Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines approximately 22 meters north and 92 meters east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey Lake Chaplain 7.5-minute quadrangle, 1989
Shaded relief generated from a lidar bare-earth digital elevation model (available from Puget Sound Lidar Consortium, http://pugetsoundlidar.ess.washington.edu/); sun azimuth 0°; sun angle 45°; vertical exaggeration 0.8
GIS by Joe D. Dragovich, Christina L. Frattali, and J. Eric Schuster
Digital cartography by J. Eric Schuster and Anne C. Olson
Editing and production by Jaretta M. Roloff, Jessica L. Czajkowski, and Alexander N. Steely

SCALE 1:24,000
1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER
contour interval 20 feet

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16.2° TRUE NORTH
APPROXIMATE MEAN DECLINATION, 2014

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