2015

History, Current Conditions, and Wetland Restoration at Killin Wetlands Natural Area, Washington County, Oregon

John A. Christy
Portland State University

Citation Details

Christy, John A., "History, Current Conditions, and Wetland Restoration at Killin Wetlands Natural Area, Washington County, Oregon" (2015). *Institute for Natural Resources Publications*. 32.
https://pdxscholar.library.pdx.edu/naturalresources_pub/32

Report to Metro

HISTORY, CURRENT CONDITION, AND WETLAND RESTORATION AT KILLIN WETLANDS NATURAL AREA, WASHINGTON COUNTY, OREGON

John A. Christy
The Wetlands Conservancy and
Oregon Biodiversity Information Center, Institute for Natural Resources,
Portland State University

August 2015

BACKGROUND

In September 2014, the Metro Natural Area Program engaged The Wetland Conservancy to develop a scientific assessment of Metro's 590-acre Killin Wetlands Natural Area. Metro acquired the lands comprising the KWNA between 2000 and 2012 with funds from two voter-approved open space bond measures. Since 2000, Metro has sought to advance natural area restoration at the site, focusing on the suppression of non-native pasture weeds and planting of native trees and shrubs in higher parts of the floodplain and its edges. Most uplands in Metro ownership have been maintained in agriculture through leased partnerships with local farmers.

Metro and its partners have observed the effects of persistent flooding at the site, which began prior to Metro's acquisition of the property. Most notable has been the decline of the once abundant Geyer willow stand, a prominent and valued feature of the site.

In February 2014, Metro convened several key scientists familiar with the wetland, and its underlying Labish soil, to discuss what was known about the Killin Wetlands and possible next steps in advancing restoration there. That discussion focused on the subsidence of organic soils, caused by artificial drainage, and led to the recommendation that a review of regional peat soil wetlands would be an important step in developing an informed plan for preserving and restoring Killin Wetlands. This report presents that review.

INTRODUCTION

Killin Wetlands Natural Area, known historically as Moore's Lake, is one of a number of low-elevation lakes or former lakes that occur in interior valleys between northwestern Oregon and southern Vancouver Island. Renowned in the early 1900s for their productive soils, these sites commanded the highest prices of any farmland in the region. Once drained, they produced a variety of specialty crops and grains, but were best known for their profitable yields of onions. Over the last 20 years, encroaching urbanization, reduced soil productivity, and competition from other agricultural regions have caused a decline in commodity prices that has reduced the agricultural value of many of these sites. Because of chronic flooding, some sites are no longer farmed and are reverting to or being restored to wetlands. While these wetlands share similar origins, conversion to agriculture, and subsequent decline in farming, their characteristics prior to drainage largely have been largely forgotten. An understanding of their original soils, vegetation, and hydrology are essential for successful wetland restoration and an understanding of their natural and cultural values. Because historical information specific to Killin Wetlands is sparse, this report summarizes accounts from a variety of other sites that occur on the same soil types. Where available, information on Killin Wetlands is given under a separate header.

Floodplain soils, particularly those with high organic content, were highly sought after by farmers throughout North America, and were known by the vernacular names "beaverdam," "lake bed," or "beaver dirt" soils (Figure 1). These soils were prominent in newspaper accounts of farming and real estate between the 1870s and 1920s. In the Pacific Northwest, beaverdam soils were primarily the hydric Labish and Semiahmoo series—the focus of this report—but also included the more widespread Wapato and Cove series (Figure 18). These soils occur intermixed on bottomlands that flood for sometimes extended periods in winter, or historically were flooded perennially by beaver dams. In Oregon, the largest and best-known sites were Coffee Lake, Killin Wetlands, Lake Labish, Lousignont Lake, Onion Flat, and Wapato Lake (Figure 19). In southwestern Washington, the Fargher Lake area and the wetlands in the Fourth Plain area of Vancouver, are currently in the planning stage as wetland mitigation sites.

Organic soils become much more widespread in western Washington and southwestern British Columbia. In addition to Semiahmoo series, western Washington also contains more than 88,000 acres of other kinds of organic soils in 14 different soil series. The lower Fraser River valley contains extensive deposits of organic soils formed in tidal marshes, lakebeds, and bogs. On rocky southern Vancouver Island, the Gulf Islands, and the San Juan Islands, lakebeds were often the only available sources of arable soil (e.g., Fulton Farm and Galey Farms in Victoria and Saanich). Throughout the region, virtually all of these sites were diked, ditched, drained, and converted to agriculture between 1870 and 1938.

Oregon's Lake Labish is the largest and best documented of these sites in the Pacific Northwest. Early publications and herbarium specimens indicate that Lake Labish, and presumably other sites with Labish and Semiahmoo soils, once supported an unusual combination of wetland vegetation typical of low-elevation interior valleys, as well as elements from both montane and coastal peatlands. General Land Office (GLO) survey records from the 1850s, descriptions in old newspapers and archival records, and current observations made at abandoned, naturally revegetating sites indicate that the original flora on these soils was distinctive, and that as far as is known, high-quality examples no longer exist. The fact that all of these historical wetland communities were extirpated makes them exceedingly rare, high-ranked targets for conservation and restoration. Killin Wetlands and Wapato Lake are now partially protected, owned respectively by Metro and the U.S. Fish and Wildlife Service, but restoration of historical conditions at these sites will be a long-term undertaking.

LANDSCAPE POSITION

Labish soils are unique to Oregon, while Semiahmoo soils extend to southwestern British Columbia. They developed in former lakes, ponds, streams, and abandoned river channels. In the northern Willamette Valley and southern Puget Trough, most of these depressions were sculpted by the Bretz or Missoula Floods (Allen et al. 1986), and most of the soils formed after the last of these disturbances about 13,000 years ago. In the northern Puget Trough and Fraser Lowlands, the soils developed after the retreat of the Fraser ice sheet about 10,000 years ago.

HISTORICAL HYDROLOGY AND VEGETATION

The most comprehensive descriptions of historical hydrology and vegetation in these wetlands, prior to artificial drainage, come from accounts written by early travelers and GLO land surveyors. Records are most robust for Lake Labish, Onion Flat, and Wapato Lake because they were the largest sites and were investigated in the first half of the 20th century by palynologists and soil scientists. Supporting evidence from these and several other sites can be used to infer a general picture of historical conditions at all of the Labish and Semiahmoo wetlands.

Hydrology

Prior to artificial drainage, Labish and Semiahmoo soils were perennially saturated. Seasonal drying probably occurred at the surface or peripheries at some sites, but peat in the subsurface rooting zone would have remained moist because of its low permeability and a high moisture-holding capacity. Water levels varied with precipitation and beaver populations, ranging from one to eight feet deep, forming shallow lakes in winter and spring. Most sites had modest inflows from small watersheds, but the northern end of Lake Labish received larger flows from the Little Pudding River, as well as upwelling from perennial springs that formed "spring holes" typical of groundwater-fed peatlands (Hyde 1852a; Williams 1878; Strozut 1959; Austin 1972). Elder (1852) described how backflow from the Tualatin River would fill Wapato Lake every winter. Most GLO surveyors described the sites as "swamps," indicating perennial groundwater and at least seasonal surface water. On Onion Flat, Ives (1852a) described a beaver dam nearly 200 feet long, "which causes a large portion of the swamp to be overflowed several feet deep...but can be easily drained." Hyde (1852a) noted that Lake Labish "could with a little expense be drained." Today, even after drainage, low-lying areas typically flood a few times every year, but rarely for more than a week or two (Fischbuck 1978).

Killin Wetlands. Trutch and Trutch (1855) provided the only known description of historical hydrology at Killin Wetlands. Their township plat map depicts the wetland as a sump, with tributary streams flowing into the wetland, but with no central channel draining into the West Fork of Dairy Creek (Figure 2). If a clearly defined channel had been present, they would have recorded it along at least one of the three sections lines that run north and south through the wetland. This indicates that water was generally distributed throughout the site. Beaver dams were not noted. The lack of a direct stream connection to Dairy Creek suggests that water entered the creek as groundwater and surface discharge at multiple points, and that Dairy Creek was probably was not as deeply incised as it is today.

Vegetation

A plant species list for Labish and Semiahmoo sites, gleaned from historical publications and herbarium records, is given in Table 1. Botanical inventory work done at Killin Wetlands in 2015 will follow in a separate report summarizing the historical and existing flora at that site.

The earliest historical accounts of Labish and Semiahmoo wetlands record only a few plant species present, but usually describe in general terms the types of wetlands or plant communities present at these sites. In 1834, Wapato Lake was described as "a kind of swamp or lake" with surrounding prairie ["plain"] "subject to be partially inundated" (Work 1923). Ives (1851) described the western end of Lake Labish as "a lake a few feet deep in the wettest season & swamp & wet prairie in the dry season." Ives (1852a) described Onion Flat as a muddy and brushy alder and willow swamp, with alder, cascara, ninebark, and spiraea. Elder (1852) described part of Wapato Lake as "smooth prairie" and "wapatoo marsh," producing "coarse grass" and rushes in summer after winter flooding receded. Hyde (1852a, b) described the central portion of Lake Labish as "nothing more than a dense willow swamp," and selected ash, willow, and vine maple as witness trees. He recorded willow trees "from 10 to 20 feet high all over [the] lake," so thick and tall that he had trouble surveying lines. Trutch and Hyde (1856) mapped most of Labish and Semiahmoo sites as lakes or swampy lakes. Lake Labish was described by Williams (1878) as "two thirds swamp," and by Anonymous (1913) as "not exactly covered by water...a great bed of decayed vegetation, swamp ash and weed growth," filled with "the barriers constructed by the beaver which infest the lake." Williams (1914) described Labish and Semiahmoo sites as being "saturated with water," tracts "covered with water so large a proportion of each year that they are either absolutely worthless to the owner or are used only for pasture during a brief period in the summer." Nelson (1919) noted standing water and "impenetrable brush and hydrophytic vegetation" at Lake Labish. Watson et al. (1923) described Labish and Semiahmoo sites as "bogs covered with a tangled growth of water-loving trees, vines, grasses, and sedges. The surface is very uneven owing to the partly fallen timber embedded within the peat or lying upon the surface, and to the tufts of grass and sedge. Drainage is poor and water stands over the surface or within a few inches of the surface." Dachnowski-Stokes (1936) wrote that Lake Labish "appears to have been, in its original condition, a marshy lake with willow-bound margins." Hayes (1939), who financed the drainage the eastern portion of Lake Labish, described it as "a swamp…covered with a heavy growth of willow trees." Collectively, these descriptions are verified by the few known photographs taken before or during drainage (Figures 3-5).

Nelson (1918, 1919) was the only historical observer to compile a list of plant species from an undrained remnant at the north end of Lake Labish. These plants are typical of cold organic soils and are now rare or extirpated from the Willamette Valley and Puget Lowlands, though still common in montane and coastal wetlands. Nelson's species, combined with databased herbarium specimens and personal observations, provide a useful list of plants that presumably were common in most Labish and Semiahmoo wetlands. A number of species in Table 1 no longer exist in the Willamette Valley, but can still be found in Washington's southern Puget Trough (Kunze 1994), making it likely that their southernmost distribution would have been in the northern Willamette Valley.

Killin Wetlands. Trutch and Trutch (1855) provided the only known description of historical vegetation at Killin Wetlands, but the information is scant. Although five section lines crossed different parts of the wetland, the surveyors only described the site as "swamp." They set two quarter section corners within the wetland, where they selected *Alnus rubra*, *Fraxinus latifolia*, and *Quercus garryana* as witness trees. No other information was recorded.

SOILS

The characteristics of Labish and Semiahmoo soils were investigated first by soil scientists and palynologists between about 1915 and 1985, making information on them 30-100 years old. Their work was described in a number of technical reports and scientific papers. Much of it involved description of soil cores, which usually extended from the surface layer to where the organic content transitioned to clay or gravel at the base of the core. In addition to revealing soil composition, cores also yield data on the depth of deposits and, if dated by analytical methods, their approximate age (Table 2). Older soil research from the Pacific Northwest universally described Labish and Semiahmoo soils as peat and muck, respectively. Because there is no international standard defining peat by its relative organic content, more recent work tends to use the term "organic soil" instead of "peat" (Rydin and Jeglum 2006). Most recent paleoecological work in the region has focused on lake sediments instead of organic soils (e.g. Pearl 1999, Minckley and Whitlock 2000).

Depth and Composition

Pearl (1999) noted that most organic deposits in the Willamette Valley formed in swamps, evidenced by their mineral soil component and compression of peats caused by seasonal drying and oxidation. Elder (1852) described the organic soil at Wapato Lake as "vegetable mould." Early federal soil surveys (e.g., Watson et al. 1923, Kocher et al. 1926, Torgerson and Glassey 1932), somewhat crude because soil science was still in its infancy, lumped these organic deposits as "muck and peat." Modern soil surveys by the Natural Resources Conservation Service (NRCS; McGee 1972, Williams 1972, Otte et al. 1974, Green 1982, Gerig 1985, SSURGO 2012) identified the currently-recognized Labish and Semiahmoo series and described their characteristics. NRCS classifies Labish soils as inceptisols (ponded humaquepts), mineral soils with up to 25% organic content, while Semiahmoo soils are fine-grained muck or mucky peats (hemic or sapric histosols). They are often interbedded or capped with lenses of sediment or pumice from centuries of floods, shifting beaver dams, and more recently, agricultural activity. The Labish series is restricted to the northern Willamette Valley, but the Semiahmoo series occurs with increasing frequency from the mid-Willamette Valley north to the Canadian border. Collectively, they cover some 10,000 acres in Oregon, and 17,000 acres in western Washington (SSURGO 2012). Labish soils have a pH of 5.5-6.2, while Semiahmoo soils range from 4.5 to 7.3. Muck soils tend to be more acid than fibrous peat, and both lack nutrients that must be supplied with fertilizers.

Depth of organic soil varies greatly among sites and within sites (e.g., Bartolome et al. 1990). Using the same layer of volcanic ash as a marker, Hansen (1941) noted that 23 feet of organic soil had accumulated at Woahink Bog in coastal Lane County, Oregon, while only 13 feet had accumulated at Bradley Bog in coastal Tillamook County during the same period of time. When the first drainage ditch was excavated at Lake Labish, the soil consisted of 8 inches of "decayed vegetation" underlain by a "powdery, black rich loam such as can only be found in swamps and lowlands inhabited by…beaver" (Anonymous 1913). Dachnowski-Stokes (1936) and Hansen (1942) independently described "peat" profiles from Lake Labish and Onion Flat, based on analysis of soil cores. While some of their terminology is now considered antiquated, I use it here for descriptive purposes. At Lake Labish, they reported three types of fibrous peat (fibric histosols), named for visible plant remains: tule (*Schoenoplectus*) peat, sedge (*Carex*) peat, and moss or "hypnum" peat.[1] Fibrous peats occurred to a depth of 10-13 feet, underlain by 3-10 feet of sedimentary peat (limnic histosols) with a considerable amount of sticks and logs, followed by sand, silt and clay below 16 feet to the bottom of the cores. At Onion Flat, they found mucky and fibrous sedge peat to a depth of 16 feet, underlain by 7 feet of sedimentary muck, under which were 10 feet of clay with organic inclusions deposited over sand, gravel and silt at the bottom of 39-foot cores. At Wapato Lake, Dachnowski-Stokes (1936) found mucky and sedimentary peat to a depth of 11.5 feet, underlain by clay. Lack of fibrous peat here indicated that the site was more of a lake than a marsh for much of its history. Hall (1936) and Strozut (1959) reported peat at Labish to a depth of 29.5 feet. Fischbuck (1978) reported peat up to 40 feet deep at Onion Flat. Rigg (1958) described profiles and composition of peat soils from multiple sites in western Washington. Palazzi (2008) described very similar profiles from Semiahmoo soils at Fargher Lake.

Ninety to 140 years of artificial drainage and farming have caused the organic component of these soils to oxidize and decompose. Technical descriptions of these soils were not published until after most sites had been drained and farmed for a decade or more. Despite its current classification as an inceptisol, the Labish series once had a higher organic content than it does today, and most likely was originally fibrous peat (fibric histosol). Williams (1914) described the Labish and Semiahmoo soils collectively as "soft brown muck, filled with partially disorganized organic matter," though Powers (1919) noted it was "rather free from raw, coarse peat." Powers (1921) and the first soil surveys classified these areas as "peat" or "peat and muck." Kocher et al. (1926) noted that the surface layer was thoroughly decomposed, presumably because of plowing and oxidation, but deeper horizons were less decomposed, coarser, and more porous. Torgerson and Glassey (1932) wrote that in at least some locations the Labish series had a surface layer “considerably decomposed but...highly fibrous, containing easily recognizable plant remains” underlain by deeper deposits of “partly decomposed highly fibrous organic matter showing much less decomposition than the material in the upper layer.” Fischbuck (1978) described the soil at Onion Flat as "just like a regular peat bog," and that one could find "old decayed vegetation,

---

1. Hypnum peat, today called "brown moss" peat, contains a variety of palustrine mosses. In Oregon, brown moss peat appears to be restricted to inland valley and mid-montane sites with moderate to low precipitation, higher summer temperatures, and higher pH. The bryoflora is typically dominated by *Drepanocladus, Hamatocaulis, Sanionia, Warnstorfia, Leptodictyum,* and *Aulacomnium,* but *Sphagnum* is conspicuously absent. Hypnum peat in Labish and Semiahmoo soils of the Willamette Valley receive about 45 inches of precipitation and have a pH of 5.6-6.2. In contrast, *Sphagnum*-rich Bergsvik and Brallier peat and muck soils along the coast may receive more than 100 inches per year and have a pH of 3.6-5.5.

seeds, straw, sticks, and stuff like that by just digging down below the plow line…it is like a bale of peatmoss…there is about a foot of topsoil, then there is about a two or three inch layer of clay…then it goes right into that peat."

Over time, farming and sedimentation changed these soils to such a degree that “some of the areas originally muck and peat are now included with other [mineral] soils” Watson et al. (1923). Similar decomposition on the Oregon coast led Smith and Shipman (1988) to reclassify Torgerson et al.'s 1949 soil classification, based on field work done in 1937-1938, from fibrous Spalding peat to Brallier and Bergsvik muck. Presumably, the larger organic material in Spalding peat had decomposed to such an extent from 50 years of drainage and farming that the soil had changed to muck or mucky peat.

Killin Wetlands. Although no peat cores are known to have been taken at Killin Wetland by soil scientists or palynologists, exploratory drilling was done for engineering purposes by the Oregon Department of Transportation (ODOT). In April 1917, the United Railways line from Portland to Wilkesboro—just south of Banks—was extended through Killin Wetland as the Gales Creek and Wilson River Railway (Anonymous 1917, Robertson 1995; Figure 6). The railroad causeway built through the wetland would have required a large amount of fill, particularly over highly compressible peat. However, no construction records for the Gales Creek extension could be found in the papers of the Burlington Northern Railroad, housed at the Oregon Historical Society.[2] United Railways ceased operation in 1923, and the Gales Creek line became a logging railroad until it was abandoned in 1950 (Weber 2002; McCamish 2005-2008). In 1952 and 1956, ODOT used the former railroad causeway to complete Highway 6, and bored a series of test holes along it to identify the structure of the underlying soil (Table 4; Figures 7 and 20). The drilling records indicate that most holes were wet to moist, some with a water table at 6 inches below the surface, while others had "plastic" or "sticky" content. Test hole 15 hit confined water at 36 feet, which rose to pour out at the surface. Organic soil was recorded as "dark brown peaty material, very soft, wet," "brown peat and muck," "black peat, wet and sticky," "organic silt, mucky stage, gray," or at least "some organic material," occurring at depths of 6-42. Some holes penetrated 7-14 feet of railroad fill, including boulders, before entering peat. Test holes 16 and 18 (1952) had no firm bottom when drilling was terminated at 42 and 48 feet, respectively. The brown, dark brown, and black colors indicate soils created under perennially wet, reduced or anaerobic conditions. Some of the gray material may have been volcanic ash, presumably from Mount Mazama, that Hansen (1944), Glenn (1965), and others used as a marker layer to date peat deposits. However, the gray layers occur at differing depths among the cores, which would indicate something other than volcanic ash. Peat recorded from the cores would have contained recognizable bits of poorly decomposed wood and other vegetation. Muck, being finer grained than peat and lacking recognizable plant parts, may have formed as organic sediment that accumulated in a lacustrine setting. Figure 20 indicates that the profiles are discontinuous between test holes, but each hole may have had a different surface elevation, and hence no correlation between holes. Data from each hole should therefore be read independent of its

---

[2] The Gales Creek and Wilson River Railway was sold to the Spokane, Portland & Seattle Railway in 1944, and eventually was owned by Burlington Northern.

neighbors. To simplify Figure 20, silt and silty clay were combined, as were any organic material and muck.

Age of Peat and Rates of Accretion

Improvements in dating technology over the last 70 years have diminished estimated rates of annual peat accretion in wetlands of the interior Pacific Northwest, indicating that peat formation is slower than it was first thought to be. For western Oregon and Washington, Hansen (1944) and Rigg (1958) estimated an average accretion rate of 0.06 inches per year. Hansen's estimate was based on chronology of Mazama and Glacier Peak ash deposits, but Rigg's work was based on early radiocarbon dating. Glenn (1965) used improved carbon dating from Lake Labish and Onion Flat to estimate an average accretion rate of 0.04 inches per year between the marker layer of Mazama ash and the basal peat deposits. At that time, he dated the ash layer to be between 6,820 and 7,125 years old. A more recent estimate for the age of Mazama ash is 7,630 years (Pearl 1999), which would further diminish rates of accretion. Clearly, Labish and Semiahmoo deposits need to be cored and calibrated again using modern dating technology, in order to obtain accurate estimates of accretion rates. Until that happens, I use the estimate of Glenn (1965) as the most recent available.

It must be remembered that these figures attempt to measure the historical rate of accumulation of buried peat, not the volume of primary productivity of organic material at the surface of the wetland. Buried peat has been compressed by water and overburden, while accreted surface material has yet to be compressed and will appear to show a faster rate of accumulation.

Killin Wetlands. Using the depths of 6-42 feet of organic material reported from the ODOT cores taken in 1952 and 1956, and Glenn's 1965 estimate from the 39-foot core at Onion Flat, the peat at Killin Wetlands could have begun to form around the time of the last Missoula Flood. A crude estimate for Killin could be 1,800-12,600 years old, but this is a guess based on a 50-year-old estimate of accretion, and should be documented by new research.

DRAINAGE AND CONVERSION TO AGRICULTURE

Since Roman times, drainage of "unimproved land" was a social imperative, providing new space to grow crops, new opportunities for farms and towns, and a means of civilizing the countryside (Williams 1970, Vileisis 1997, Murton 2008). Until the widespread availability of steam dredge technology around 1900, farmers in the Pacific Northwest recognized the potential of Labish and Semiahmoo wetlands for pasture or farming, but they lacked the means to drain them effectively. At first these sites were avoided in favor of better-drained soils. Ditching by hand and horse-drawn draglines reportedly began at Coffee Lake 1859 and Wapato Lake in the 1870's (Metro, Smith 1976). Boosters described the Fargher Lake area in Clark County, Washington, as being "extensive tracts of swale land…covered with a dense growth of brush, which, being slashed and burned at the proper time, is comparatively easy to clear" (Anonymous

1878). Around 1910, improved technology, private investment capital, and the formation of drainage districts ushered in a major land boom for beaverdam soils, lasting until the Great Depression. A steam dredge completed the largest project at Lake Labish in 1913-1914 (Anonymous 1913, 1914; Figure 5). Two-thirds of Labish and Semiahmoo sites in Washington County had been converted by 1925 (Watson et al. 1923, Jessup and Powers 1925). Drainage at Wapato Lake, reportedly begun about 1875 (Anonymous 1889, Bancroft 1888, Smith 1976), accelerated after the lakebed was subdivided (Anonymous 1898), and was completed between 1928 and 1938 (Williams 1914, Anonymous 1936, Wapato Improvement District 1952).

The first step in conversion from wetland to farmland was excavation of a central main ditch or drain, after which all stumps and woody vegetation were cleared, stacked, and burned. Lateral ditches and networks of drain tile were then installed to complete the system (Williams 1914, Powers 1919, Watson et al. 1923, Figure 8). Later local projects included dikes and pumping stations, though these already had been used for centuries in Europe. Large quantities of fertilizer and lime were needed to keep these soils productive, but they quickly became the most valuable farmland in the Willamette Valley. Land that had sold for $1 an acre prior to drainage was worth up to $1,000 an acre by 1914 (Anonymous 1913, Strozut 1959). Beets, cabbage, carrots, celery, lettuce, onions, rhubarb, peppermint, horseradish, potatoes, green peppers, radishes, spinach, tomatoes, small grains, and hay were grown on these soils, with onions being the most widespread and most profitable crop (Watson et al. 1923, Kocher et al. 1926, Torgerson and Glassey 1932, Hall 1936). Constant and costly maintenance is required to keep dikes and pumps in good repair, and ditches cleared of silt, aquatic vegetation, and beaver dams. In coastal areas, tide gates are an additional part of infrastructure that require periodic maintenance or replacement.

Killin Wetlands. Drainage at Killin Wetlands began in 1892: "Hon. Benton Killin and others, are draining a swamp in the northwestern part of the county formerly known as Moore's Lake. The tract to be reclaimed contains 600 or 700 acres, of which 500 belong to Mr. Killin. The ditch or canal in its upper course is six feet wide by three and a half deep, but at the outlet it is very much larger. The land is of the variety known hereabouts as beaver-dam." (Anonymous 1892)[3]. Weber (2002) noted that the area between the central ditch and today's Highway 6 was never cleared, and supported a stand of willows prior to 1940. When Harriet Killin, Benton Killin's widow, died in 1937, the property passed to their daughter Estelle and her husband Frank Kistner. The Kistners cleaned the central ditch with a dragline about every 3 years, and grew spring oats on the drained land. By 1940, they had abandoned the wetter eastern portion of the wetland, which grew up in willows. They laid drain tiles and continued to farm the higher western end of the wetland, in the vicinity of what later became a stand of ash trees.

---

[3] Weber (2002) indicated that Benton Killin (1842-1905) began to drain the wetland in the 1870s with the help of students from Pacific University. However, deed records at the Washington County Assessor's Office indicate that Killin bought the property in stages between 1890 and 1892, and his heirs continued to consolidate ownership in the area after his death until 1907. No records could be found in the Pacific University Archives, or in the Killin Family Papers at the Oregon Historical Society, concerning his land purchases or drainage project. Killin offered to sell some "beaver-dam onion land in parcels to suit" (Morning Oregonian, 9 and 11 Sep 1902: 8).

SURFACE SUBSIDENCE

Shrinkage or "wastage" occurs in all artificially drained peaty soils, including diked salt marsh, causing the surface layer to subside. Subsidence was first recognized in European drainage projects in the 1600s (Williams 1970; Hutchinson 1980; Darby 1983). Drying causes shrinkage and decomposition of organic material, in turn increasing soil bulk density and reducing pore space. Compaction by farming equipment, and erosion by wind and water contribute to the subsidence. Deeper drainage, deep plowing, and deep-rooted crops enhance the effect. The better the drainage, the more rapid the subsidence (Darby 1983), requiring higher dikes and more pumping. Waltham (2000) observed that "peat is a wasting asset – it can be drained and farmed only at the cost of its inevitable destruction." Pumping of groundwater can also cause surface subsidence, but this is not known to be a factor at Killin Wetlands.

Rates of Subsidence

Less than 20 years after drainage, Powers (1932a) reported that the surface of Lake Labish had subsided 2 feet. Dachnowski-Stokes (1936) and Hansen (1942) both estimated that surface elevations at all Labish and Semiahmoo sites had subsided between 3.2 and 26 feet. Gravelle (1998) estimated that overall subsidence at Lake Labish had been 7 to 8 feet since drainage in 1914. Unfortunately, none of these authors documented how they measured the subsidence. If accurately reported, an overall rate of subsidence would have been about 1.2-1.5 inches per year, the same as reported by Schmitz (2002). These rates are consistent with estimates compiled for 149 similar temperate zone wetlands in the US, Europe, and New Zealand that have been drained for about the same period of time (Pronger et al. 2014). Rates of subsidence are rapid after initial drainage, and diminish over time as organic material oxidizes and soils are compacted. They also vary from place to place and year to year depending on temperature and moisture.

Killin Wetlands. No estimates or measurements of subsidence exist for Killin Wetlands, but its rate presumably was similar to those described above from the Pacific Northwest.

Secondary Causes of Subsidence

Mining of peat for fuel and soil additives has caused extensive areas of subsidence, or sometimes complete ecosystem collapse in fens and bogs, primarily in Canada and the U.K, but also in British Columbia (Hebda and Biggs 1981, Howie et al. 2008). Peat fires, most accidental or caused by lightning, but others part of agricultural practices (e.g., Rojstaczer & Deverer 1995) also cause subsidence by consuming organic material in the soil. Both of these kinds of disturbance create areas of open water.

Killin Wetlands. In August 1917, a spark from construction of the Gales Creek and Wilson River Railroad started a peat fire in Killin Wetlands that burned more than 7.2 acres to a depth of

2-3 feet (Anonymous 1921). The fire would have created a body of open water unusable for pasture or farming, compounding the effect of surface subsidence caused by drainage. Harriet Killin, widow of Benton Killin, unsuccessfully sued the railroad for damages. The lawsuit is not mentioned in the Killin Family Papers housed at the Oregon Historical Society, and because the case was dismissed by the judge, no record was kept in the Washington County Circuit Court. Weber (2002) indicated that the fire occurred on the south side of the railroad grade, on property now owned by the Hartmann family. At some point after 1937, the Kistners cut and burned willows on the north side of the railroad grade, starting another peat fire. The date, location, and extent of this burn are not known.

Peat and climate change

Carbon flux in peatlands is an important component of climate change models. As a fixed repository of organic material, hydrated peat stores carbon that would otherwise contribute to global warming. Accreting peat functions as a carbon sink that removes carbon from the atmosphere. In contrast, the decaying peat of drained and subsiding wetlands is a source of carbon, released to the atmosphere in the form of carbon dioxide and methane. From this point of view, rehydration of dried peat, and resumption biomass accumulation from organic plant material would have a positive influence as a carbon sink (e.g., Miller and Fujii 2011).

Decline and opportunity

Declining commodity prices, soil productivity, and chronic flooding caused by inadequate drainage are steadily eroding the value of farmed organic soils in the Pacific Northwest. In urbanizing areas, some Labish and Semiahmoo sites such as Coffee Lake have been fragmented by roads and other development to such an extent as to limit restoration options. Some sites like Minthorn Springs and Hearthwood Wetland in Milwaukie, Oregon, are relictual fragments of larger, formerly farmed sites that have been paved over.

Rising maintenance costs make farming of Labish and Semiahmoo sites more and more expensive. Dikes built on organic soils become unstable as the soils beneath them compress and subside (Miller et al. 2008). Many diked coastal marshes have subsided to the point where they are below sea level. Though not universal, a boom-and-bust cycle has occurred in many drainage districts in both North America and Europe. Neglected infrastructure becomes too expensive to upgrade or replace, forcing either government intervention or abandonment (Williams 1970; Darby 1983). Economic distress of the Wapato Improvement District enabled the U.S. Fish and Wildlife Service to purchase most of the Wapato Lake bed (Harrington 2001), leading to the creation of the Wapato Lake National Wildlife Refuge. Small portions of Coffee Lake and Lake Labish have been restored, and several Semiahmoo sites in Clark County, Washington, are currently being converted to wetland mitigation banks.

Killin Wetlands. Drainage infrastructure at Killin Wetlands began to be neglected about 1940 (Weber 2002), enabling the self-restoration of hydrology and native vegetation, followed by its purchase by Metro in 2002 for conservation purposes.

RESTORATION OPTIONS – SHRUB SWAMP OR LAKE?

As with any restoration of drained wetland, the essential first step is to return water to the site. This is usually done by blocking drainage ditches, breaking drain tile, and constructing weirs if needed. In cases where drainage has damaged or destroyed peat, it is imperative to permanently rehydrate the soil to prevent further oxidation and subsidence, and to revitalize self-regulating peat-forming processes (e.g., Quinty and Rochefort 2003, Howie et al. 2008). Perennially wet soil will increase porosity and reduce bulk density, both of which will improve chemical and biological processes needed for successful wetland restoration. Rehydration and accretion of plant litter will increase the organic content of the soil, and also act as a carbon sink for greenhouse gases. To maximize the benefits of carbon storage in a changing climate, it is essential to keep peat soils hydrated, and rehydrate those that have been artificially drained. The surface layer eventually will rebound (Quinty and Rochefort 2003), but it is a long-term process. Sometimes it is not possible to restore a peatland to historical conditions, and alternative kinds of habitat need to be contemplated (Burton & Hodgson 1987, Rydin and Jeglum 2006). Drainage can permanently alter pH, chemical composition, and water-holding capacity in peat soils.

Unfortunately, because virtually all Labish and Semiahmoo wetlands were drained and have subsided surfaces, we have no occurrences to use as reference sites to guide restoration.
Once soil is rehydrated, managers must decide how to deal with flooding caused by surface subsidence. They have limited choices: (1) allow the site to begin a long-term, self-designed restoration beginning with open water, (2) engineer structures such as cells and terraces to achieve shorter-term goals that enhance specific emergent or woody vegetation targets (Figures 15 and 16), or (3) keep the wetland drained, continue farming portions for wildlife food crops, and excavate ponds and plant willows to create wetland features on a more restricted scale (Figure 17). The tradeoffs for these approaches are the long-term alternative of naturally-designed features, versus potentially shorter-term investments in infrastructure, planting, and artificially-designed features.

Advantages of self-designed restoration are naturally-formed habitats and low cost, in contrast to more expensive engineered habitats that may not be successful (e.g., Cornu 2005). The first two options enable long-term and large-scale reversal of subsidence by allowing accretion of sediment and organic material, but the third option would limit this process to the confines of the excavated ponds. Continued farming of these soils will only cause further subsidence. Construction of cells and terraces require investment and maintenance, and usually result in a stairstep pattern of flooded areas on subsided surfaces, and upslope habitats that if dry enough can provide habitat for reed canary grass and other invasives. Constructing new dikes or maintaining old ones over subsiding organic material may be problematic over time. Bates and Lund (2013) calculated a mean annual probability of dike failure of 5%, an acceptable risk to recovery of emergent marsh if subsidence is shallow, but a liability to investments in infrastructure and planting if subsidence is deep, because deep flooding would preclude marsh recovery. The third option of planting and excavating ponds creates small-scale areas of restoration, but does nothing to raise groundwater levels that can provide landscape-scale habitat benefits. However, in urbanizing areas that are already fragmented with development or multiple ownerships, such as at Lake Labish, Coffee Lake, and Minthorn Springs, small-scale restoration is the only feasible alternative.

Flooding

Although most Labish and Semiahmoo sites contained some open water historically, accounts indicate that they also contained significant portions of dense willow and ash swamp (Figures 3-5). Upon rehydration, peatlands whose surfaces have subsided because of artificial drainage, fire, and peat mining inevitably will flood to form ponds and lakes. Flooding is often enhanced by returning beavers that plug drainage ditches and raise water levels even higher. Flooding may be deep enough to kill existing woody vegetation, or prevent it from reestablishing except around the perimeter of the wetland. This has happened at a Labish soil restoration site at Hillsboro Landfill (Latimer 2015), and restoration at Wapato Lake will pose similar challenges.

Killin Wetlands. Between 1940 and 1990, after drainage began to be neglected, but before extensive flooding by beavers, much of the site had reverted to native willow and ash swamp (Christy 2012; Figures 9 and 10, top). Today, almost all of this vegetation is dead, and the site is a lake up to 6 feet deep (Figure 9, bottom). Aquatic bed vegetation is proliferating, consisting primarily of *Nuphar*, *Potamogeton*, *Persicaria*, *Brasenia*, *Elodea*, *Utricularia*, *Ceratophyllum*, and *Myriophyllum* (Figure 11).

When I first examined Killin Wetlands in 1990 and 1991, beavers had created several small dams along the central drainage ditch, and water in portions of the willow swamp was knee-deep. Weber (2002) noted that siltation had impeded drainage more than the beaver activity, but today beavers are the primary drivers of restoration at Killin Wetlands. Since 2002, successive dams of increasing height have raised water levels incrementally, turning the former willow swamp into a lake. Expansion of the lake into former wetland areas, as indicated by hydric soils, shows that the water level is approaching its historical maximum, except for extreme events. Neighbors mentioned an episode in the 1970s when water overtopped Highway 6, and ODOT records from 1956 described flood debris on the road and a length of roadbed that had slumped.

Water levels at Killin Wetlands are not static. Air photos indicate a steady rise in water level between 2002 and 2011, a drop in 2013 and 2014, and a rise again in 2015. (Figure 12) Presumably, the failure of a 5-6 foot tall beaver dam seen by the author at the outlet in 2012 was responsible for the drop. Remains of this dam are still visible in 2015, and it has been replaced by a 4-5 foot tall dam built on slightly higher ground about 10 feet upstream from the older dam (Figure 13, top). The bottom photo in Figure 13 shows a faint silt line on dead ash trees at Killin, indicating an episode of high winter water that was approximately 2 feet above the present surface of the lake. This may date from the same event that left drift debris hanging from trees 2 feet above the surface of the water, seen by Christy in 2012. If true, failure of the beaver dam seen in 2012 would have occurred during a subsequent high water event. These episodes illustrate the kind of intense hydraulic pressure on beaver dams that causes them to fail. In April 2015, the dam had water spilling over the top, but by June beavers had contained this with a mud berm along the top of the dam, raising the water level another 6-10 inches. Beavers dredged the mud from 1-2 feet of sediment that has accumulated at the bottom of the pool behind the dam, creating muddy water that is clearly visible in air photos (Figure 14). Air photos from 2015 indicate that the new beaver dam has raised water levels to an all-time high since first observations were made by the author in 1990.

Reversal of Subsidence

Estimated rates of vertical accretion and years needed to reverse subsidence are given for selected wetlands in Table 2. Most studies of subsidence reversal focus on either diked tidal marsh or mined peatland, and examine the rate of surface rebound by accretion by sediments and organic material. Rates of accretion vary depending on hydrology, temperature, and water chemistry (Burton & Hodgson 1987). The studies do not take into account compression of layers as they accumulate over time, which subsidence reversal will be slower than biomass production figures indicate.

In an area of previously mined for peat in the Fraser River Delta, Hebda and Biggs (1981) reported accretion rates of 0.3-3.2 inches per year. After restoration of water on the site, Howie et al. 2008 reported an average accretion rate of 0.6-0.7 inches. Accretion in tidal marsh has been studied extensively worldwide in relation to sea level rise, and rates approximate those reported for interior wetlands, although they usually receive larger inputs of mineral sediments delivered by rivers (Drexler 2011). Because few studies of accretion have been done in nontidal wetlands in the Pacific Northwest, a few examples of tidal references are included here. Thom (1992) estimated rates of 0.09-0.2 inches per year for tidal marshes in the Pacific Northwest, while researchers in the Sacramento-San Joaquin observed accretion rates of 1.6-3.6 inches per year (Rojstaczer and Deverer 1995, Miller et al. 2008, Bates and Lund 2013, Foster et al. 2014).

For the Pacific Northwest, I have not been able to locate references documenting the rate of vertical accretion by individual freshwater plant species. Primary productivity can be used as a surrogate for vertical accretion, and the literature on productivity is extensive. As would be expected, litter from plants with greater amounts of supporting tissue decompose more slowly and contribute more litter than plants with less tissue. Mitsch and Gosselink (1986) reported that swamp and riparian forests far exceeded other wetland types in production of total organic matter. As would be expected, productivity of large emergent marsh species (e.g., *Phragmites, Typha, Schoenoplectus*) exceeded that of smaller species. Rydin and Jeglum (2006) reported that productivity of trees, and presumably shrubs, is substantial in eutrophic swamps, when compared to more nutrient-poor peatlands. Loaiza (2008) found that broadleaf and aquatic bed vegetation trapped more sediment than graminoids and shrubs, and attributed this to the greater surface area of submerged plants. Hart et al. (2013) found that deciduous trees delivered greater amounts of litter to streams than did conifers. Pollock et al. (2015) reported that beaver ponds can accumulate deposits of sediment, herbaceous, and woody debris up to 3 feet deep, potentially reversing nearly half of the surface subsidence estimated to have occurred in drained Labish wetlands.

In addition to natural accretion from plant litter, surfaces can also be artificially raised with dredge spoils or soil taken from old dikes, but this material will settle over time and lose some of the elevation gained (Cornu and Sadro 2002, Cornu 2005, Bates and Lund 2013). Clearly, decades or centuries are required to reverse subsidence. Bates and Lund (2013) calculated that an accretion rate of 1.6 inches per year will take 50 years to reverse subsidence of 7 feet, and 130 years to reverse subsidence of 16 feet. They postulated that if subsidence reversal rates are close to ongoing subsidence rates, the time needed to restore historical elevation will be about the same as the time elapsed since the wetland was drained. These time frames also apply to Labish and Semiahmoo sites that have experienced similar subsidence over the same period of time.

Water Depth and Vegetation

I have not been able to locate estimates of optimal depth to water table for local species, but a detailed study by Jeglum (1971) serves as a useful surrogate (Table 3). The species selected from Jeglum include those reported historically from Labish and Semiahmoo sites (Table 1), species that potentially could occur in restored habitat at these sites, or species not in our flora but presumably approximating tolerances of local species. In the Pacific Northwest, aquatic bed vegetation thrives at depths between 1 and 6 feet of water. Optimal water depth for emergent marsh species has been reported at 9.8-22 inches, preferably with fluctuating levels during the growing season (Rydin and Jeglum 2006, Miller et al. 2008, Foster et al. 2014). Rydin and Jeglum (2006) recommend a stable water level close to the surface to restore fens and bogs. Despite the ability of willows, ash, and spiraea to survive winter flooding in the Pacific Northwest, perennial flooding usually kills them. To support regrowth of trees and shrubs, Rydin and Jeglum (2006) recommend a water table 8-12 inches below the surface during the growing season, but Jeglum (1971) indicated that some species of willow can tolerate a water table closer to the surface (Table 3).

Killin Wetlands. In 1990 and 1991, willows at Killin were thriving with water slightly below to slightly above the ground surface, though in places it was knee-deep (Figures 9 and 10). In 2015, a few scattered willows and spiraea at Killin continue to produce weak sprouts in water 3-5 feet deep. Most of these shrubs appear to have been killed between 2005 and 2008 (Figure 12), presumably after submersion for at least one full growing season. To my knowledge, water depth around shrubs was not measured during that period, so we don't know the exact depth that was lethal, but presumably it was between 2-3 feet.

Recommendations

With no intervention, Killin Wetlands is an evolving, dynamic example of a site that has revegetated naturally after maintenance of drainage infrastructure ceased. Prior to about 2000, without planting or other management activity, native vegetation grew spontaneously under existing hydrological conditions to create a shrub swamp very similar to those described in the historical record prior to drainage projects. The advent of beavers then caused a complete habitat shift to open water. Today, beavers are the primary drivers of hydrology and vegetation at Killin, raising local groundwater to levels possibly not seen in 125 years. Although a lake has replaced the high-structure willow swamp habitat that existed prior to 2005, several lines of evidence suggest that historically the site may have alternated between willow swamp and lake: (1) the long-term cyclical boom-and-bust nature of beaver activity, (2) the presence of Semiahmoo muck soil that formed in a lacustrine environment, (3) ODOT flood records for Highway 6, and (4) the former name of Moore's Lake.

Beginning in the 1940s, the water at Killin Wetlands has steadily risen and is now probably at its highest level since 1890. Metro's neighbors are not entirely unhappy with this state of affairs. At least 6 duck hunting blinds have been built on the lake, two of them on Metro property, and two neighbors have created boat launches on their property. These are recreational assets that would not be available if the lake level was low or nonexistent. In addition to recreational opportunities, flooding of a former field on the Spiering property is creating a wapato marsh, some plants of which are beginning to migrate into Metro ownership. Wapato, along with most of the aquatic bed species, probably have not been abundant at Killin for over a century. The lake is habitat for a variety of fish, amphibians, and waterfowl.

Beavers are keystone agents of wetland recovery, and their presence at Killin should be encouraged. As beaver populations and locations fluctuate over time, regulated by available food, water supply, and sedimentation, they create varied landforms that enrich regional biodiversity (Pollock et al. 2015). However, there are challenges to maintaining beavers at Killin. Because the flooding has killed almost all of the willows in a few short years, the beavers' food supply now is severely depleted. The primary structure holding the existing beaver dam in place is an ash log about 18 inches in diameter. The remaining components of the dam are sticks, none over about 1 inch in diameter, and mud. At the time of our visits to Killin, the beavers' diet appeared to be primarily *Cornus sericea* and aquatic macrophytes. Another high-water event will probably destroy the present dam at some point, and the water level will drop again. Metro can let this happen naturally, or install some kind of control structure at the outlet where the beaver dam is located. A complicating factor is that half of the present beaver dam is on the neighboring Hartmann property, making control of the lake level problematic. However, the Hartmanns have made a boat landing on their property adjacent to Highway 6, and may have built one of the hunting blinds on Metro property. If this is true, they must enjoy recreational access to the lake, and potentially could be partners in any maintenance of lake levels.

Restoration of willow and ash swamp as seen in the 1990s will require lowering or removal of the beaver dam, or installation of a "beaver deceiver" at the dam to reduce water levels to a depth that will support regrowth of willow and ash. This will dewater much of the present footprint of rehydrated soils, including the incipient wapato marsh developing on the Spiering property. A better alternative would be to concentrate planting willow and aspen[4] around the periphery of the lake, particularly in the southwestern corner of the Moore property, which is the closest plantable location in Metro ownership that is contiguous to the center of beaver activity at Killin.

Improved access to the outlet of Killin Wetlands for monitoring beaver dams, or to artificially regulate lake levels, would be from the north, leading through the Moore property from the gate on Highway 6. This access would require replacement of the derelict farm bridge across Dairy Creek, and cutting a trail from the southwestern corner of the property to the area of old dredge spoils by the beaver dam. The dredge spoils could be used to plug the incised outlet stream, and plantings there could replace the current stand of reed canary grass.

For complete control of the lake and its outlet, Metro could acquire the Hartmann property north of Highway 6, or negotiate a cooperative management agreement with them. In addition, acquisition of the flooded portion of the Spiering property would enable Metro to plant an abundance of willow and aspen around the foot of the slopes above the new wapato marsh. This would be a preferable alternative to lowering the lake level and dewatering much of the wetland. Willow, aspen, and ash could also be planted around the periphery of the upper part of Killin Wetlands also, but this area was not examined as part of this project. The upper wetland is far removed from the primary beaver activity at the outlet area, but new planting there would lure beavers in that direction. In addition, Metro could build beaver and bird viewing blinds at several locations along the lake, though currently the only opportunity for access is on Metro ownership below the Kistner barn. Incidentally, we did hear from neighbors of someone trapping beavers in the vicinity of the bridge along Cedar Canyon Road, presumably trespassing on Metro property.

Acknowledgements

I am grateful to Curt Zonick (Metro) and Esther Lev (The Wetlands Conservancy) for the opportunity to work on this project. Megan Garvey of The Wetlands Conservancy provided a much-needed second pair of eyes at Killin Wetlands, as well as her expertise on amphibians and invertebrates. Jim Morgan (formerly Metro), took an early interest in Killin Wetlands. Dallas Weber (former long-time resident of Kistner Farm) provided first-hand knowledge of the history of Killin Wetlands. Ken Bierly (Oregon Department of State Lands, retired) and the Oregon Community Foundation funded GLO research. Shane Latimer provided access to the Hillsboro Landfill project and shared his experience gained while moving and replanting a Labish wetland. The Oregon Flora Project (Linda Hardison, Thea Cook, Katie Mitchell) and Oregon State University Herbarium (Aaron Liston, Richard Halse) provided information on herbarium collections past and present. George Kral provided personal botanical collection data. The Oregon State University Special Collections and Archives, the Oregon Historical Society, the

---

[4] Aspen is the most favored food of beavers, and is present elsewhere on the Moore property (Christy 2012). In general, it is rare in the northern Willamette Valley.

Oregon State Library (Dave Hegeman), the Pacific University Archives (Eva Guggemos), the Washington County Museum (Karen Lange), the Willamette University Archives (Ashley Toutain, Mary McRobinson), the Oregon Department of Transportation (Susan Ortiz, Laura Wilt), and the Willamette Heritage Center (Kylie Pine) provided access to their archival collections. The Washington County Department of Assessment and Taxation provided access to historical land records.

LITERATURE CITED

Allen, J.E., M. Burns & S.C. Sargent. 1986. Cataclysms on the Columbia, a layman's guide to the features produced by the catastrophic Bretz floods in the Pacific Northwest. Timber Press, Portland, Oregon. 213 pp.

Anonymous. 1878. The Eaton Settlement, Clarke County, W.T. The West Shore (Portland, Oregon), 1 July 1878: 2.

Anonymous. 1889. Joseph Gaston. Pp. 331-332 in: History of the Pacific Northwest: Oregon and ashington, Vol. 2. North Pacific History Company, Portland, Oregon. 708 pp.

Anonymous. 1892. Noteworthy news, clippings from some of the newspapers of this section. Evening Capital Journal (Salem), 19 September 1892: 2.

Anonymous. 1898. Subdivision and sale of Wapato Lakebed. The Hillsboro Argus, 10 November 1898: 3.

Anonymous. 1913. Lake Labish will soon be ready for farmers. The Daily Capital Journal, 20 December 1913, Christmas edition, Sec. 3: 21

Anonymous. 1914. Marion lands reward; California rancher drains 2000 acres Lake Labish. Oregonian, 24 February 1914: 3, col. 4.

Anonymous. 1917. New road progressing. The Timberman 18 (8): 48N.

Anonymous. 1921. Harriet B. Killin vs. Wilson River and Gales Creek Railway [sic]. The Hillsboro Argus, 28 November 1921: 3.

Anonymous. 1936. Wapato Lake considered for wildlife refuge. Oregonian, 5 January 1936: 8.

Austin, G.B.J. 1972. Annals of the S.W.R. Jones family, 1853-1972.

Bancroft, H.H. 1888. History of Oregon. Vol. 2. 1848-1888. From: The Works of Hubert Howe Bancroft, Vol. 30. The History Company, San Francisco. 808 pp.

Bartolome, J.W., D.C. Erman & C.F. Schwartz. 1990. Stability and change in minerotrophic peatlands, Sierra Nevada of California and Nevada. Research Paper PSW-198. USDA Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. 11 pp.

Bates, M.E. & J.R. Lund. 2013. Delta subsidence reversal, levee failure, and aquatic habitat—a cautionary tale. San Francisco Estuary and Watershed Science 11 (1): 1-20.

Burton, R.G.O. & J.M. Hodgson (eds.). 1987. Lowland peat in England and Wales. Soil Survey Special Survey 15, Harpenden. Soil Survey of England and Wales.

Christy, J.A. 1990, 1991, 1993, 2002. Field notes, Killin Wetlands. (6 Sep 1990, 16 May 1991, 24 Jul 1991, 19 Aug 1993, 30 May 2002).

Christy, J.A. 2012. Botanical inventory of Moore property, and observations on adjacent Killin Wetland. Report to Metro. 29 pp.

Cornu, C.E. 2005. Restoring Kunz Marsh. South Slough NERR Coastal Resource Management Series. CRMS-2005-1. Coos Bay, Oregon.

Cornu, C.E. & S. Sadro. 2002. Physical and functional responses to experimental marsh surface elevation manipulation in Coos Bay's South Slough. Restoration Ecology 10: 474-486.

Dachnowski-Stokes, A.P. 1936. Peat land in the Pacific Coast states in relation to land and water resources. U.S. Department of Agriculture Miscellaneous Publication 248: 1-68.

Darby, H.C. 1983. The Changing Fenland. Cambridge University Press, London. 267 pp.

Drake, J. 1910. Photograph of Lake Labish, exact location unknown. Oregon Historical Society bb012858.

Drexler, J.Z. 2011. Peat formation processes through the millennia in tidal marshes of the Sacramento-San Joaquin Delta, California, USA. Estuaries and Coasts. DOI 10.1007/s12237-011-9393-7.

Elder, R. 1852. General Land Office survey notes for subdivision of Township 2 South, Range 4 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Wapato Lake].

Fischbuck, C. 1978. Interview with Chester Fischbuck, 2 April 1978. Washington County Museum Archives, Accession LOH 78-176.3. [Taped oral interview and typed transcript].

Foster, M., E. Variano, M. Levy & B. Stanford. 2014. Subsidence reversal through marsh re-establishment on Twitchell Island. ePosters. Accessed 14 Feb 2015. http://www.eposters.net/pdfs/subsidence-reversal-through-marsh-re-establishment-on-twitchell-island.pdf

Gerig, A.J. 1985. Soil survey of Clackamas County area, Oregon. USDA Soil Conservation Service. 293 pp. + maps.

Glenn, J.L. 1965. Late Quaternary sedimentation and geologic history of the north Willamette Valley, Oregon. Ph.D. dissertation. Oregon State University, Corvallis. 231 pp.

Gravelle, M. 1998. Ancient lakebed lies rich in legend. Salem Statesman Journal, 19 April 1998: 1, 6.

Green, G.L. 1982. Soil survey of Washington County, Oregon. USDA Soil Conservation Service. 138 pp. + maps.

Hall, B. 1936. Lake Labish: 1500 acres of black gold. Oregonian, Magazine Section, 10 September 1939: 9.

Hansen, H.P. 1941. Paleoecology of two peat deposits on the Oregon coast. Oregon State Monographs, Studies in Botany 3: 1-31.

Hansen, H.P. 1942. A pollen study of lake sediments in the lower Willamette Valley of western Oregon. Bulletin of the Torrey Botanical Club 69: 262-280.

Hansen, H.P. 1944. Further pollen studies of peat bogs on the Pacific Coast of Oregon and Washington. Bulletin of the Torrey Botanical Club 71: 627-636.

Harrington, P. 2001. Onions sink, but lake may rise again. The Oregonian, 1 March 2001: B4.

Hart, S.K., D.E. Hibbs & S.S. Perakis. 2013. Riparian litter inputs to streams in the central Oregon Coast Range. Freshwater Science 32: 343-358.

Hayes, J.O. 1939. Testimony of J.O. Hayes. Pp. 62-96 in: Transcript of Record, Case No. 9069. United States District Court of Appeals for the Ninth Circuit. Ladd & Bush, a corporation, Appellant, J.O. Hayes, Appellee. Upon appeal for the District Court of the United States for the Northern District of California, Southern Division. Parker Printing Co., San Francisco. 140 pp.

Hebda, R.J. & W.G. Biggs. 1981. The vegetation of Burns Bog, Fraser Delta, southwestern British Columbia. Syesis 14: 1-20.

Howell, T.J. 1897-1903. A flora of northwest America. Vol. 1. Phanerogamae. Fascicles 1-7. 816 pp. Portland, Oregon.

Howie, S.A., T.G. Munson, R.J. Hebda, J.K. Jeglum, P.H. Whitfield & R.A. Dakin. 2008. Restoration of Burns Bog, Delta, British Columbia. Pp. 51-55 in: Pristine Mire Landscapes. Proceedings of the 13th International Peat Congress. Tullamore, Ireland.

Hutchinson, J.N. 1980. The record of peat wastage in the East Anglian fenlands at Holme Post, 1848-1978 A.D. Journal of Ecology 68: 229-249.

Hyde, G.W. 1852a. General Land Office survey notes for subdivision of Township 6 South, Range 2 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Lake Labish].

Hyde, G.W. 1852b. General Land Office survey notes for subdivision of Township 6 South, Range 1 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Lake Labish].

Ives, B. 1851. General Land Office survey notes for east boundary of Township 6 South, Range 3 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Lake Labish].

Ives, B. 1852a. General Land Office survey notes for subdivision of Township 2 South, Range 1 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Onion Flat].

Ives, W. 1852b. General Land Office survey notes for subdivision of Township 1 South, Range 1 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Beaver Swamp, Beaverton].

Ives, W. 1852c. General Land Office survey notes for subdivision of Township 3 South, Range 1 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Coffee Lake (Black Swamp)].

Jeglum, J.K. 1971. Plant indicators of pH and water level in peatlands at Candle Lake, Saskatchewan. Canadian Journal of Botany 49: 1661-1676.

Jessup, L.T. & W.L. Powers. 1925. Preliminary drainage survey, Willamette Valley. U.S. Bureau of Agricultural Engineering and Oregon Agricultural Experiment Station. Typescript, Oregon State University Library. 46 pp + map.

Kocher, A.E, E.J. Carpenter & K.S. Taylor. 1926. Soil survey of Clackamas County, Oregon. USDA Bureau of Soils. Pp. 1633-1701.

Kral, G. 2014. Personal communication with John Christy. Ash Creek Forest Management, Tigard, Oregon.

Kunze, L.M. 1994. Preliminary classification of native, low elevation, freshwater wetland vegetation in western Washington. Washington Natural Heritage Program, Department of Natural Resources, Olympia. 120 pp.

Latimer, S. 2015. Interview with Shane Latimer, Latimer Environmental LLC. February 2015.

Loaiza, E. 2008. Effects of different vegetation cover types on sediment deposition in the Tivoli North Bay tidal freshwater marsh, Hudson River, New York. Cary Institute of Ecosystem

Studies. 7 pp.

McCamish, B. 2005-2008. The Abandoned Gales Creek & Wilson River Railroad and the Consolidated Timber Company. Abandoned Railroads of the Pacific Northwest. Accessed March 2015. http://www.brian894x4.com/GalesCreekandWilsonRiverRR.html

McGee, D.A. 1972. Soil survey of Clark County, Washington. USDA Soil Conservation Service. 113 pp. + maps.

Miller, R.L. & R. Fujii. 2011. Re-establishing marshes can turn a current carbon source into a carbon sink in the Sacramento-San Joaquin Delta of California, USA. Pp 1-34 in: D. A. Contreras (ed.), River Deltas: Types, Structures and Ecology. Nova Science Publishers, Inc.

Miller, R.L., M.S. Fram, R. Fujii & G. Wheeler. 2008. Subsidence reversal in a re-established wetland in the Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science 6 (3): 1-20.

Minckley, T. & C. Whitlock. 2000. Spatial variation of modern pollen in Oregon and southern Washington, USA. Review of Palaeobotany and Palynology 112: 97-123.

Mitsch, W.J. & J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold, New York. 539 pp.

Murton, J. 2008. Creating order: the liberals, the landowners, and the draining of Sumas Lake, British Columbia. Environmental History 13: 92-125.

Nelson, J.C. 1918. Notes on the flora of Lake Labish, Oregon. Torreya 18: 191-195.

Nelson, J.C. 1919. The grasses of Salem, Oregon and vicinity. Torreya 19: 216-227.

Otte, G.E., D.K. Setness, W.A. Anderson, F.J. Herbert & C.A. Knezevich. 1974. Soil survey of the Yamhill area, Oregon. USDA Soil Conservation Service. 130 pp. + maps.

Palazzi, L. 2008. [Fargher Lake] Wetland Mitigation Bank: Soils and Hydrology Report. Pacific Rim Soil & Water, Inc. Olympia, WA. 44 pp. + appendices.

Pearl, C.A. 1999. Holocene environmental history of the Willamette Valley, Oregon: insights from an 11,000-year record from Beaver Lake. M.S. Thesis. University of Oregon, Eugene. 150 pp.

Peterson, W. 1986. Lake has rich soil, past. Keizer Times, 15 August 1996: 12.

Pollock, M.M., G. Lewallen, K. Woodruff, C.E. Jordan & J.M. Castro (eds.). 2015. The beaver restoration guidebook: working with beaver to restore streams, wetlands, and floodplains.

Version 1.0. U.S. Fish and Wildlife Service, Portland, Oregon. 189 pp. http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Beaver.asp

Powers, W.L. & T.A.H. Teeter. 1916. The drainage of "white lands" and other wet lands in Oregon. Bulletin of the Oregon Agricultural College Experiment Station 137: 1-80.

Powers, W.L. 1919. Preliminary report on the improvement of marsh lands in western Oregon. Bulletin of the Oregon Agricultural College Experiment Station 157: 1-32.

Powers, W.L. 1921. Preliminary report on the management of Willamette Valley soils. Bulletin of the Oregon Agricultural College Experiment Station 185: 1-12.

Powers, W.L. 1930. Chemical characteristics and utilization of some peat soils in northwestern United States. Northwest Science 4: 16-17.

Powers, W.L. 1932a. Subsidence and durability of peaty lands. Agricultural Engineering 13: 71-72.

Powers, W.L. 1932b. Characteristics of dispersable organic colloids in peat. Journal of Agricultural Research 44: 97-111.

Pronger, J., L.A. Schipper, R.B. Hill, D.I Campbell & M. McLeod. 2014. Subsidence rates of drained agricultural peatlands in New Zealand and the relationship with time since drainage. Journal of Environmental Quality 43: 1442-1449.

Quinty, F. & L. Rochefort. 2003. Peatland restoration guide. Second edition. Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Engergy. Québec, QC. 106 pp.

Rigg, G.B. 1958. Peat resources of Washington. Bulletin of the Washington Division of Mines and Geology 44: 1-272.

Robertson, D.B. 1995. Encyclopedia of Western Railroad History. Vol. 3, Oregon and Washington. Caxton Printers Ltd., Caldwell, Idaho.

Rojstaczer, S. & S.J. Deverel. 1995. Land subsidence in drained histosols and highly organic mineral soils of California. Soil Science Society of America Journal 59: 1162-1167.

Rydin, H. & J.K. Jeglum. 2006. The Biology of Peatlands. Oxford University Press. 343 pp.

Schmitz, J. 2002. Hard times on Lake Labish. Onion World, August 2002. Columbia Publishing Co.

Smith, H.L. 1976. Wonderful wappato, the wild potato, an Oregon vignette. Smith, Smith &

Smith Publishing Co., Lake Oswego. 16 pp.

Smith, P.R. & J.A. Shipman. 1988. Soil survey of Clatsop County, Oregon. USDA Soil Conservation Service. 272 pp. + maps.

SSURGO. 2012. National Soil Survey spatial database. USDA Natural Resources Conservation Service, United States Department of Agriculture.

Steusloff, C. 1980. Lake Labish: from swamp to productive farmland. Capital Press, 21 November 1980.

Strozut, G. 1959. Black gold: the story of Lake Labish. Marion County History 5: 47-49.

Thom, R.M. 1992. Accretion rates of low intertidal salt marshes in the Pacific Northwest. Wetlands 12: 147-156.

Torgerson, E.F. & T.W. Glassey. 1932. Soil survey of Marion County, Oregon. USDA Bureau of Chemistry and Soils. Series 1927, number 32: 1-46.

Torgerson, E.F., J. McWilliams & C.J. McMurphy. 1949. Soil survey, Astoria area, Oregon. USDA Bureau of Plant Industry, Soils, and Agricultural Engineering. Series 1938, Number 20: 1-80.

Trutch, J.W. & J. Trutch. 1855. General Land Office survey notes for subdivision of Township 2 North, Range 4 West, Willamette Meridian. USDI Bureau of Land Management, Oregon State Office, Portland. [Killin Wetlands].

Trutch, J.W. & G.W. Hyde. 1856. Preston's sectional and county map of Oregon and Washington, west of the Cascade Mountains. Compiled from United States Surveys and other authentic sources. Scale 1:506,880. A.H. Burley Stationer, Chicago.

Vileisis, A. 1997. Discovering the unknown landscape: a history of America's wetlands. Island Press, Washington, D.C. 433 pp.

Waltham, T. 2000. Landmark of geology in the East Midlands: peat subsidence at the Holme Post. Mercian Geologist 15: 49-51.

Wapato Improvement District. 1952. By-laws, landowners notice, and amended articles of incorporation of Wapato Improvement District. 40 pp.

Watson, E.B., E.C. Eckmann, A.L. Fluharty & C.V. Ruzek. 1923. Soil survey of Washington County, Oregon. USDA Bureau of Soils. 51 pp. + map.

Weber, D. 2002. Interview with Dallas Weber at Killin/ Kistner farmhouse, Killin Wetland. Jim

Morgan, Curt Zonick, and John Christy present.

Williams, E. 1878. Historical atlas map of Marion and Linn Counties, Oregon. Edgar Williams & Co., San Francisco.

Williams, I.A. 1914. Drainage of farm lands in the Willamette and tributary valleys of Oregon. Mineral Resources of Oregon 1 (4): 3-81.

Williams, M. 1970. The draining of the Somerset Levels. Cambridge University Press, London. 288 pp.

Williams, L.H. 1972. Soil survey of the Marion County area, Oregon. USDA Soil Conservation Service. 132 pp. + maps.

Work, J. 1923. John Work's journey from Fort Vancouver to Umpqua River, and return, in 1834. Oregon Historical Quarterly 24: 238-268.

Table 1. Historical and existing vascular flora of Killin Wetland and related Labish soil sites, 1871-2015. Herbarium acronyms: HPSU = Portland State University; ID = University of Idaho; NY = New York Botanical Garden; OSC = Oregon State University; US = Smithsonian Institution; WS = Washington State University; WTU = University of Washington.

Taxon	**Family**	**Native/ Exotic**	**Historical (all Labish sites)**	**Current (Killin)**	**Source**
Acer circinatum	Sapindaceae	N	Labish 1852	–	Hyde 1852a; Powers 1919; Strozut 1959; Steusloff 1980
Agrostis exarata	Poaceae	N	Labish 1916	–	Nelson 1918, 1919
Agrostis oregonensis	Poaceae	N	Labish 1916	–	OSC (Nelson)
Alisma triviale	Alismataceae	N	Killin 1991	–	Christy 1991
Alnus incana ssp. *tenuifolia*	Betulaceae	N	Labish 1916	–	OSC (Peck)
Alnus rubra	Betulaceae	N	Beaver Swamp [Beaverton] 1852; Coffee Lake 1852; Onion Flat 1852; Killin 1855	2015	Ives 1852a, b, c; Trutch & Trutch 1855; Powers 1919; Strozut 1959; Steusloff 1980; Peterson 1986)
Alnus viridis ssp. *sinuata*	Betulaceae	N	Killin n.d.	–	Kral 2014
Azolla sp. (sterile)	Salviniaceae	N	Killin	2015	
Beckmannia syzigachne	Poaceae	N	Labish 1916, Killin 1993	–	OSC (Peck); Christy 1993
Betula glandulosa	Betulaceae	N	Labish 1917	–	OSC (Gorman)
Betula pumila	Betulaceae	N	Labish 1871-1922	–	OSC, WS (Gorman, Howell, Nelson, Peck); Howell 1897-1903; Nelson 1918 (as *B. hallii*)
Bidens cernua	Asteraceae	N	Killin 1990, 1991	–	Christy 1990, 1991
Brasenia schreberi	Cabombaceae	N	Killin	2015	
Callitriche heterophylla var. *bolanderi*	Plantaginaceae	N	Labish 1917	–	OSC (Peck)
Callitriche stagnalis	Plantaginaceae	E	Labish 1947	–	OSC (Peck)
Callitriche verna	Plantaginaceae	N	Labish 1947, 1955	–	ID, OSC (Furtick, Peck)

Caltha palustris	Ranunculaceae	N	Labish 1893-1917	–	OSC, WTU (Gorman, Howell, Nelson, Peck); Howell 1897-1903; Nelson 1918
Canadanthus modestus	Asteraceae	N	Labish 1922	–	OSC (Nelson)
Carex sp.					Powers 1930, 1932a, 1932b
Carex aperta	Cyperaceae	N	Labish 1917	–	OSC (Peck); Nelson 1918
Carex aquatilis var. *dives*	Cyperaceae	N	Labish 1916; Killin 1993	–	OSC (Nelson); Nelson 1918; Christy 1993
Carex cusickii	Cyperaceae	N	Labish 1917, 1918; Killin 1991	–	NY, OSC (Nelson, Peck); Nelson 1918; Christy 1991
Carex densa	Cyperaceae	N	Labish 1916	–	OSC (Nelson)
Carex echinata ssp. *echinata*	Cyperaceae	N	Labish 1916	–	OSC (Nelson); Nelson 1918 (as *C. interior*)
Carex exsiccata	Cyperaceae	N	Killin 1991	–	Christy 1991
Carex obnupta	Cyperaceae	N	Killin 1990	2015	Christy 1990
Carex pachystachya	Cyperaceae	N	Labish 1916	–	OSC (Peck)
Carex scoparia	Cyperaceae	N	Labish 1916	–	OSC (Peck)
Centaurium erythraea	Gentianaceae	E	Labish 1947	–	OSC (Peck)
Ceratophyllum demersum	Ceratophyllaceae	N	Killin	2015	
Cicuta douglasii	Apiaceae	N	Killin 1993	–	Christy 1993
Collinsia grandiflora	Plantaginaceae	N	Labish 1916	–	OSC (Peck)
Collinsia multiflora	Plantaginaceae	N	Labish 1916	–	OSC (Nelson)
Comarum palustre	Rosaceae	N	Labish 1917	–	OSC (Peck); Nelson 1918
Cornus sericea	Cornaceae	N	Killin 1990	2015	Christy 1990
Crataegus douglasii	Rosaceae	N	Killin 1991	–	Christy 1991
Crataegus gaylussacia	Rosaceae	N	Labish 1917	–	OSC (Gorman)
Cyperus erythrorhizos	Cyperaceae	N	Killin 1990	–	Christy 1990
Eleocharis acicularis	Cyperaceae	N	Killin 2002	–	Christy 2002
Eleocharis obtusa	Cyperaceae	N	Killin 1991	–	Christy 1991
Eleocharis ovatus	Cyperaceae	N	Killin 2002	–	Christy 2002
Eleocharis palustris	Cyperaceae	N	Killin 1991	2015	Christy 1991
Elodea canadensis	Hydrocharitaceae	N	Labish 1955; Killin 2012	2015	OSC (Furtick); Christy 2012
Epilobium brachycarpum	Onagraceae	N	Labish 1922	–	OSC (Nelson)

Epilobium ciliatum ssp. *watsonii*	Onagraceae	N	Labish 1916	–	Nelson 1918
Equisetum arvense	Equisetaceae	N	Labish 1916	–	Nelson 1918; Dachnowski-Stokes 1936
Equisetum x *litorale*	Equisetaceae	N	Labish 1916	–	WS (Nelson)
Equisetum palustre	Equisetaceae	N	Labish 1921	–	OSC, WTU (Peck)
Eriophorum gracile	Cyperaceae	N	Labish 1895	–	OSC (Howell)
Fraxinus latifolia	Oleaceae	N	Coffee Lake 1852; Labish 1852; Onion Flat 1852; Killin 1855, 1990	2015	Hyde 1852a, b; Ives 1852a, c; Trutch & Trutch 1855; Anonymous 1913; Strozut 1959; Steusloff 1980; Peterson 1986; Christy 1990
Glyceria borealis	Poaceae	N	Killin 1993	–	Christy 1993
Glyceria occidentalis	Poaceae	N	Labish 1917	–	OSC (Peck)
Gnaphalium palustre	Asteraceae	N	Killin 1991	–	Christy 1991
Helenium autumnale	Asteraceae	N	Labish 1947	–	OSC (Peck)
Heterocodon rariflorus	Campanulaceae	N	Labish 1916	–	WS (Nelson)
Heuchera chlorantha	Saxifragaceae	N	Labish 1916	–	OSC (Peck); Nelson 1918
Impatiens capensis	Balsaminaceae	E	Killin	2015	
Juncus spp.	Juncaceae	N	Beaver Swamp [Beaverton] 1852	–	Ives 1852b
Juncus acuminatus	Juncaceae	N	Labish 1917	–	OSC (Peck)
Juncus effusus ssp. *effusus*	Juncaceae	E	Killin 2002	–	Christy 2002
Juncus hemiendytus var. hemiendytus	Juncaceae	N	Labish 1916	–	OSC, WS, WTU (Nelson, Peck); Nelson 1918 (as *Juncus uncialis*)
Leersia oryzoides	Poaceae	N	Killin 1990	–	Christy 1990
Lemna minor	Araceae	N	Killin 1991	–	Christy 1991
Lonicera involucrata var. *involucrata*	Caprifoliaceae	N	Killin 2002	–	Christy 2002
Ludwigia palustris	Onagraceae	N	Killin 1991	2015	Christy 1991
Lysichiton americanus			Labish		Strozut 1959
Lysimachia thyrsiflora	Primulaceae	N	Labish 1892	–	OSC, WTU (Howell)

Malus fusca	Rosaceae	N	Coffee Lake 1852; Killin 1991	–	Ives 1852c; Christy 1991
Mentha longifolia	Lamiaceae	E	Labish 1930	–	OSC (Ellis)
Menyanthes trifoliata	Menyanthaceae	N	Labish 1916, 1917	–	OSC, WS (Gorman, Nelson); Nelson 1918
Micranthes oregana	Saxifragaceae	N	Labish 1893-1916	–	NY, OSC, US, WS, WTU (Howell, Peck)
Mitella caulescens	Saxifragaceae	N	Labish 1916	–	OSC (Peck)
Myosurus minimus	Ranunculaceae	N	Labish 1917	–	WTU (Peck); Nelson 1918
Myriophyllum spicatum	Haloragaceae	E	Killin	2015	
Nuphar polysepala	Nymphaeaceae	N	Beaver Swamp [Beaverton] 1852; Labish 1910; Killin 2012	2015	Ives 1852b; Drake 1910; Dachnowski-Stokes 1936; Christy 2012
Nymphaea odorata ssp. *odorata*	Nymphaeaceae	E	Killin	2015	
Persicaria amphibia	Polygonaceae	N	Killin 2002	–	Christy 2002
Persicaria hydropiper	Polygonaceae	E	Killin 1991	–	Christy 1991
Persicaria hydropiperoides	Polygonaceae	N	Killin 1990	2015	Christy 1990
Phalaris arundinacea	Poaceae	E	Killin 1991	2015	Christy 1991
Phragmites australis	Poaceae	?	Labish 1916	–	OSC, WS (Nelson); Nelson 1918, 1919
Physocarpus capitatus	Rosaceae	N	Onion Flat 1852; Killin 2002	2015	Ives 1852a; Christy 2002
Plagiobothrys figuratus var. *figuratus*	Boraginaceae	N	Labish 1917	–	OSC (Gorman)
Platanthera dilatata var. *leucostachys*	Orchidaceae	N	Labish 1916	–	WS (Nelson)
Polygonum polygaloides ssp. *confertiflorum*	Polygonaceae	N	Labish 1916	–	OSC (Peck)
Populus trichocarpa	Salicaceae	N	Labish	–	Strozut 1959
Potamogeton spp.	Potamogetonaceae	N	?	2015	Dachnowski-Stokes 1936
Potamogeton berchtoldii	Potamogetonaceae	N	Killin 2012	2015	Christy 2012

Potamogeton epihydrus	Potamogetonaceae	N	Killin	2015	
Potamogeton natans	Potamogetonaceae	N	Killin 2012	2015	Christy 2012
Potentilla norvegica	Rosaceae	N	Labish 1922	–	OSC (Nelson)
Quercus garryana	Fagaceae	N	Killin 1855	2015	Trutch & Trutch 1855
Ranunculus aquatilis var. *aquatilis*	Ranunculaceae	N	Labish 1916	–	OSC (Peck)
Ranunculus aquatilis var. *diffusus*	Ranunculaceae	N	Labish 1917	–	WS (Gorman)
Ranunculus arvensis	Ranunculaceae	E	Labish 1916	–	OSC, WS (Nelson, Peck); Nelson 1918
Ranunculus flammula var. *flammula*	Ranunculaceae	N	Labish 1917	–	WS (Gorman)
Ranunculus repens	Ranunculaceae	E	Labish 1916	–	OSC (Peck)
Rhamnus purshiana	Rhamnaceae	N	Onion Flat 1852; Labish 1917, Killin	2015	WS (Gorman); Ives 1852a
Rhododendron columbianum	Ericaceae	N	Labish 1916	–	OSC, WS (Nelson, Peck); Nelson 1918
Rorippa curvisiliqua	Brasssicaceae	N	Killin 1991	–	Christy 1991
Rosa pisocarpa	Rosaceae	N	Killin 1990, 1991, 2012	2015	Christy 1990, 1991, 2012
Sagittaria latifolia	Alismataceae	N	Wapato Lake 1852; Killin	2015	Elder 1852
Salix spp.	Salicaceae	N	Beaver Swamp [Beaverton] 1852; Coffee Lake 1852; Labish 1852; Onion Flat 1852; Wapato Lake 1852	2015	Hyde 1852a, b; Ives 1852a, b, c; Elder 1852; Anonymous 1913; Powers 1919, 1930, 1932a, 1932b; Hall 1936; Strozut 1959; Steusloff 1980; Peterson 1986
Salix geyeriana	Salicaceae	N	Labish 1916, 1917; Killin 1991	2015	OSC (Peck); Nelson 1918; Christy 1991
Salix hookeriana	Salicaceae	N	Killin 1990, Labish 1991	–	WTU (Zika); Christy 1990
Salix lasiandra var. *lasiandra*	Salicaceae	N	Killin 1990, Labish 1991	–	WTU (Zika); Christy 1990
Salix pedicellaris	Salicaceae	N	Labish 1916, 1917	–	OSC (Gorman, Peck)

Salix scouleriana	Salicaceae	N	Labish 1991	–	WTU (Zika)
Salix sitchensis var. *sitchensis*	Salicaceae	N	Killin 2012	–	Christy 2012
Sambucus nigra ssp. *caerulea*	Adoxaceae	N	Killin	2015	
Schoenoplectus cf. *tabernaemontani*	Cyperaceae	N	Labish 1916	–	WS (Nelson); Powers 1919; Dachnowski-Stokes 1936
Scirpus microcarpus	Cyperaceae	N	Killin 2002	–	Christy 2002
Scutellaria galericulata	Lamiaceae	N	Labish 1917	–	WS (Nelson); Nelson 1918
Senecio hydrophiloides	Asteraceae	N	Labish 1895-1917	–	OSC, NY, WS (Gorman, Howell, Peck);); Howell 1897-1903 (as *S. oreganus*)
Senecio integerrimus var. *exaltatus*	Asteraceae	N	Labish 1916	–	OSC (Peck); Nelson 1918
Sisyrinchium bellum	Iridaceae	N	Labish 1916	–	OSC (Peck)
Solanum dulcamara	Solanaceae	E	Killin	2015	
Sparganium emersum	Typhaceae	N	Killin 1990	2015	Christy 1990
Spiraea douglasii var. *douglasii*	Rosaceae	N	Beaver Swamp [Beaverton] 1852; Coffee Lake 1852; Onion Flat 1852; Killin 1990	2015	Ives 1852a, b, c; Powers 1919; Christy 1991
Spirodela polyrrhiza	Araceae	N	Killin	2015	
Symphyotrichum hallii	Asteraceae	N	Labish 1947	–	OSC (Peck)
Tiarella trifoliata var. *trifoliata*	Saxifragaceae	N	Labish 1916	–	OSC (Peck)
Torreyochloa pallida var. *pauciflora*	Poaceae	N	Killin 1991	–	Christy 1991
Typha spp.	Typhaceae	N	Beaver Swamp [Beaverton] 1852	–	Ives 1852b; Strozut 1959
Typha latifolia	Typhaceae	N	Labish 1916, Killin 1990	–	WS (Nelson); Powers 1919; Christy 1990
Utricularia gibba	Lentibulariaceae	N	Killin	2015	
Viola blanda	Violaceae	N	Labish 1884	–	HPSU (Howell)
Viola palustris	Violaceae	N	Labish 1917	–	OSC (Peck)

Vulpia microstachys	Poaceae	N	Labish 1916	–	OSC (Peck)
Wolffia borealis	Araceae	N	Killin	2015	

Table 2. Estimated depth, age, and rates of accretion and subsidence for selected peatlands.

Site	Habitat	Depth of peat (ft)	Estimated age (yr), per Glenn (1965)	Rate of subsurface accretion (in/yr), per Glenn (1965)	Years since drainage	Estimated subsidence (ft)	Rate of subsidence (in/ yr)	Rate of surface accretion (in/ yr)	Sources
East Anglia, UK	bog/ fen	22	—	—	128	13	0.2-1.9	—	Hutchinson 1980
Burns Bog, BC	bog/ fen		—	—	—	—	—	0.3-3.2	Hebda & Biggs (1981)
Killin Wetland, OR	**swamp**	**6-42**	**1,800-12,600**	**0.04**	**123**	**—**	0.8-1 (1.5)	—	**ODOT 1952, 1956**
Coffee Lake, OR	swamp	—	—	—	156	—	0.8-1 (1.5)	—	Metro (sign at Boeckman Rd bridge)
Lake Labish, OR	swamp	19.7-29.5	5,910-8,850	0.04	101	16-26	0.8-1 (1.5)	—	Dachnowski-Stokes (1936), Hall (1936), Hansen (1942), Strozut (1959), Glenn (1965), Gravelle (1998)
Onion Flat, OR	swamp	39.4-40	11,820-12,000	0.04	125	16-26	0.8-1 (1.5)	—	Dachnowski-Stokes (1936), Hansen (1942), Glenn (1965), Fischbuck (1978)
Wapato Lake, OR	swamp	11.5	3,450	0.04	80-140	3.3-6.6	0.8-1 (1.5)	—	Dachnowski-Stokes (1936)
Sacramento-San Joaquin Delta, CA	tidal marsh	59	6,000-7,000	0.04	85-150	4-19.7	0.3-4.6	1.6-3.6	Rojstaczer & Deverer (1995), Miller et al. (2008), Bates and Lund (2013), Foster et al. (2014)
Oregon and Washington	tidal marsh	—	—	—	—	—	—	0.09-0.2	Thom (1992)
South Slough, OR	tidal marsh	—	—	—	105	2.7	—	—	Cornu & Sadro 2002, Cornu 2005

Table 3. Depth to water table for selected peatland species (Jeglum 1971). Species in brackets are not present locally.

Depth to water table (in)	Taxon
31 or more	*Cornus sericea*
	Salix [*bebbiana*]
	Calamagrostis canadensis
	Geum macrophyllum
	Juncus balticus
	Mentha canadensis
	Poa palustris
	Pyrola asarifolia
	Stachys pilosa
	Symphyotrichum
24-31	[*Picea mariana* -- seedlings to saplings to > 4 inches diameter]
	Alnus [*rugosa*]
	Ledum [*groenlandicum*]
	Salix [*myrtillifolia*]
	Equisetum arvense
	Viola palustris
16-23	*Drosera rotundifolia*
	Eriophorum [*spissum*]
8-15	[*Larix laricina* -- seedlings to saplings to 4 inches diameter]
	Betula glandulosa
	Salix [4 species, none local)
	Caltha palustris
	Carex [3 species, none local]
	Cinna latifolia
	Glyceria striata
	Phalaris arundinacea
	Poa pratensis
	Scutellaria galericulata
	Urtica dioica
0-7	*Salix* [2 species, none local]
	Agrostis scabra
	Bidens cernua

	Calamagrostis stricta ssp. *inexpansa*
	Carex aquatilis
	Cicuta [*bulbifera*]
	Epilobium ciliatum
	Eriophorum chamissonis
	Eriophorum gracile
	Lycopus uniflorus
	Manyanthes trifoliata
	Potentilla anserina
Depth below water surface (in)	**Taxon**
0-7	*Carex utriculata*
	Glyceria grandis
	Persicaria amphibia
	Sagittaria latifolia
	Sium suave
	Sparganium eurycarpum
8-15	*Ceratophyllum demersum*
	Lemna minor
	Utricularia vulgaris
16-24	*Eleocharis palustris*
	Equisetum fluviatile
	Hippuris vulgaris
	Glyceria borealis
	Myriophyllum sibiricum
	Myriophyllum verticillatum
	Nuphar [*variegatum*]
	Phragmites australis
	Potamogeton gramineus
	Potamogeton pusillus
	Potamogeton [*vaginatus*]
	Scirpus acutus
	Sparganium natans
	Typha latifolia
	Utricularia intermedia
	Utricularia minor

Table 4. Composition of drill cores taken by ODOT along grade of former Gales Creek and Wilson River Railway, for construction of Highway 6, 1952 and 1956. Soil & Geological Exploration Log, Constructions Division. Survey stations ran from west to east.

Test hole	Survey station	Date	Depth (ft)	Composition and comments
10	2460+30	Apr 1952	0-2	topsoil
			2-25	plastic clay
			25-42	some organic material
			42	end of hole
11	2461+80	Apr 1952	0-6	topsoil
			6-42	clay, brown silty, medium plasticity, drills easy, grayish green
			42	end of hole
12	2463+70	Apr 1952	0-4	topsoil
			4-9	grayish-blue silty clay, drills easy, moist to sticky
			9-15	peat, black, drills easy, wet to sticky
			15-20	greenish blue highly plastic silty clay, dry, drills easy
			20-26	clayey silt
			26-32	clayey silt, wetter
			32-42	brown silt
			42	end of hole, all clay
9	2467+65	Jun 1952	0-2	black sandy clay, wet to muck, easy drilling
			2-5	brown silty clay, muck, easy drilling
			5-13	brown peat, muck, easy drilling
			13-33	gray silty clay, wet, firm & tough spots, tough drilling
			33	end of hole
13	2468+45	Apr 1952	0-5	topsoil
			5-20	clay, reddish brown, sticky
			20-25	clay, reddish brown, sticky, wetter
			25-36	red clay, highly plastic
			36-42	gray clay
			42	end of hole
15	2473+90	Apr 1952	0-7	railroad fill, boulders, etc.
			7-20	peat, black, wet & sticky, drills easy
			20-36	[illegible] or [illegible], silt content increases, organic silt, low plasticity, mucky stage, gray
			36	water augered from hole
			36-42	stopped drilling, water pouring from hole, diluting sediments
			42	end of hole

16	2483+35	Apr 1952	0-9	railroad fill
			9-24	brown silty clay, medium to high plasticity, moist
			24	moisture increases
			24-42	gray clay, pea gravel & sand near bottom, no firm bottom
			42	end of hole
18	2487	Jul 1956	0-10	reddish brown silty clay, moist, firm, water level in hole at 6"
			10-30	dark brown peaty material, very soft, wet, able to shove steel down without turning
			30-33	light brown sandy clay, very firm
			33	end of hole
19	2488	Jul 1956	0-7	reddish brown silty clay, fairly firm, moist, water level in hole at 6"
			7-23	brown peaty material, very soft, wet, able to shove steel down without drilling
			23-29	brown silty clay, very soft, wet, easy drilling
			29-33	brown sandy clay shale, very firm, hard drilling
			33	end of hole
17	2493+35	Apr 1952	0-14	railroad fill
			14-20	peat, brown, moist & sticky, drills easy
			20-23	organic silt, low plasticity, drills easy
			23-24	less organic, increase in clay, moist & sticky, blue
			24-48	soil refuses to clean from auger
			48	end of hole
18	2503+40	Apr 1952	0-13	railroad fill
			13-20	peat, brown, moist & sticky, drills easy
			20-48	clayey silt, bluish gray, medium plastic, drills easy
			48	end of hole, no firm bottom

Figure 1. Road sign in Beaverton, Oregon, 2015. There were about 80 acres of muck land in this vicinity, farmed by 27 families who raised onions, rhubarb, horseradish, and asparagus. "The land sells readily at $230 per acre. The muck is from two to twenty feet deep" (The Oregon Scout (Union, Oregon), 4 November 1887: 7). One of the more prominent farmers was Augustus Fanno.

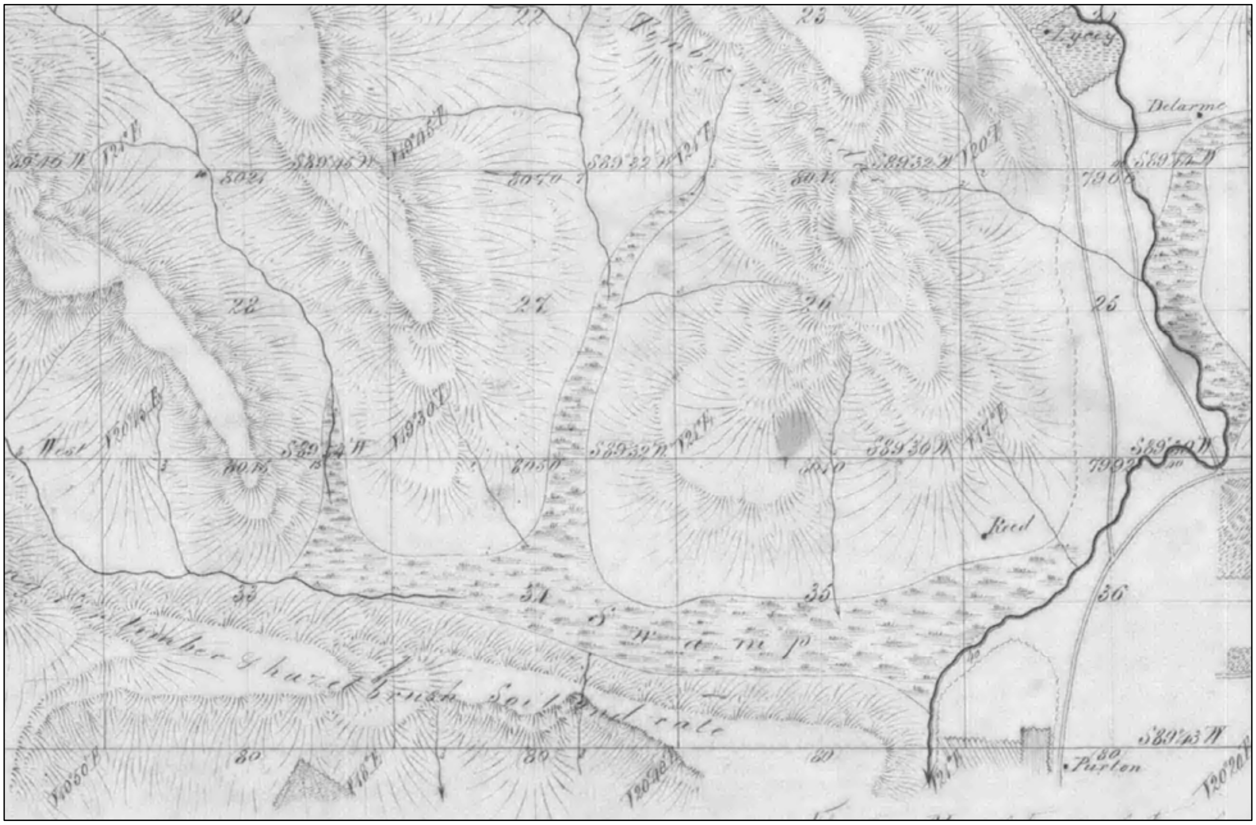


Figure 2. Killin Wetlands, General Land Office plat map of 1855. Note lack of central stream channel or direct connection to West Fork of Dairy Creek. (Trutch and Trutch 1855).

Figure 3. Excavation of the Labish Ditch, eastern half of Lake Labish, 1913. Note dense shrub swamp and trees. (Powers and Teeter 1916).

Figure 4. Portion of Lake Labish prior to drainage, exact location unknown, 1910. Note open water, aquatic bed vegetation, and willow stands. Photograph by June Drake. (Oregon Historical Society bb012858).

Figure 5. Steam dredge, eastern half of Lake Labish, 1913. (Powers and Teeter 1916).

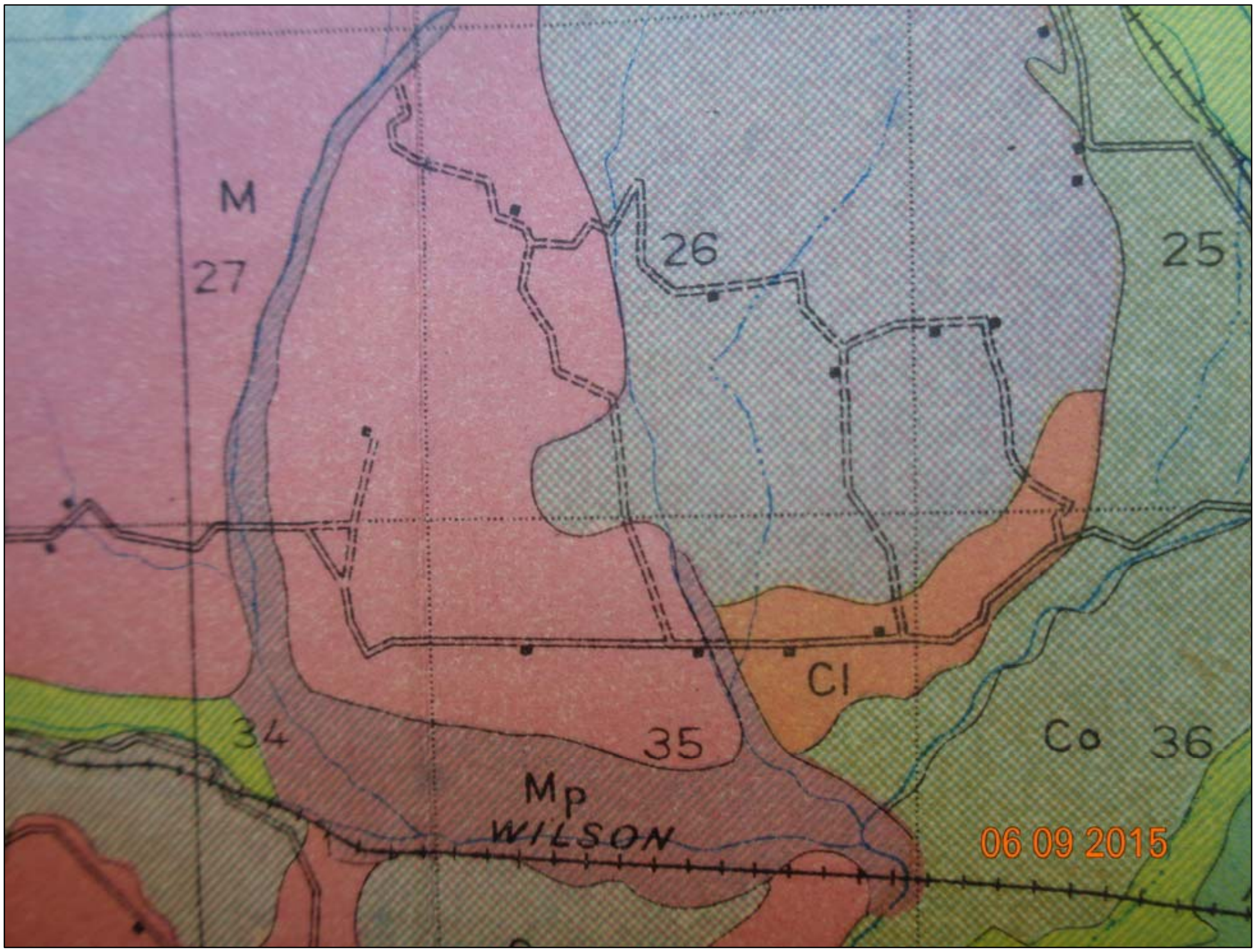


Figure 6. Killin Wetlands, showing extent of muck and peat soil (Mp), advance Bureau of Soils map of 1919. Note Gales Creek and Wilson River Railway, constructed in 1917 and replaced in 1956 by Highway 6. (Watson et al. 1923).

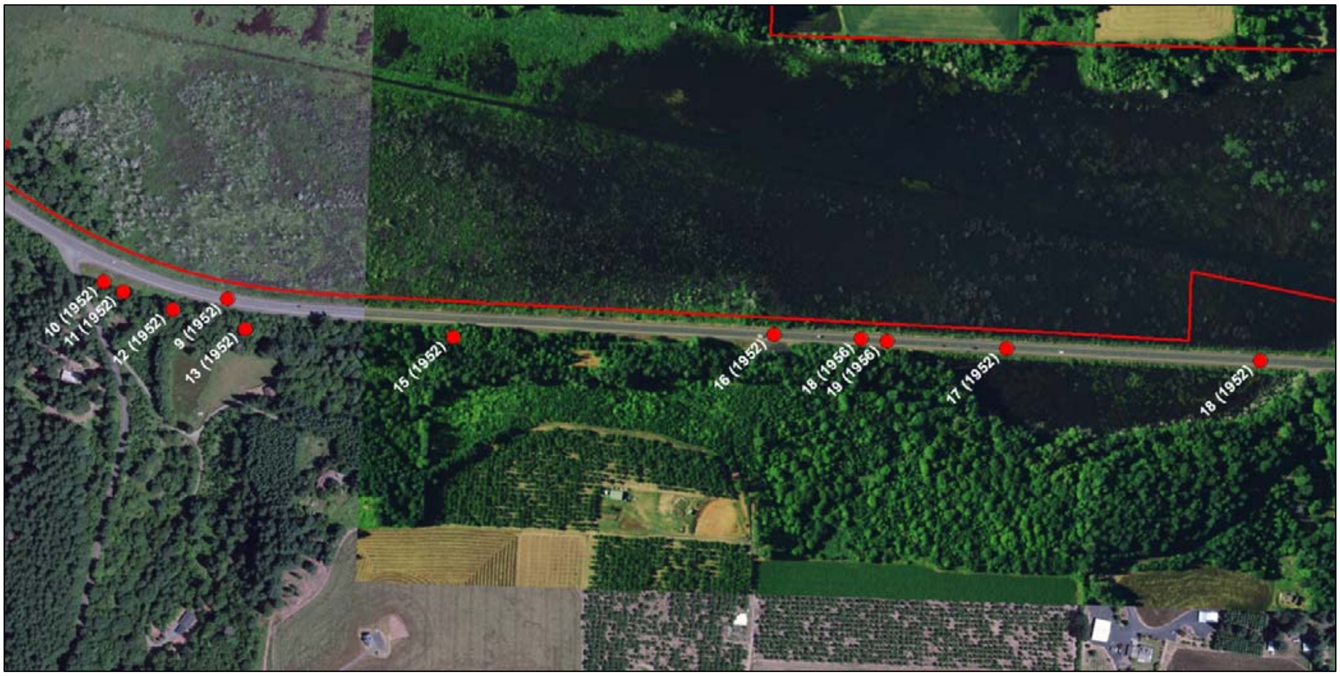


Figure 7. Approximate positions of ODOT boreholes (red dots) along grade of former Gales Creek and Wilson River Railway through Killin Wetlands, for construction of Highway 6, 1952 and 1956. See Figure 20 for core profiles.

Figure 8. Top: Labish Ditch, lakebed, and onion crop, 1990. Bottom: Lousignot Ditch and lakebed (2015). Photos by author.

Figure 9. Killin Wetlands. Top: natural revegetation, looking NW, 1990. Bottom: same view after ca. 15 years of flooding by beaver, 2015. Photos by author.

Figure 10. Killin Wetlands. Top: natural revegetation, looking NE, 1990. Bottom: same view after ca. 15 years of flooding by beaver, 2015. Photos by author.


06 17 2015

06 17 2015

Figure 11. Killin Wetlands. Flood-killed ash (top) and willows (bottom), with expanding aquatic beds of *Potamogeton* and *Brasenia*, 2015. Photos by author.

Figure 12. NAIP imagery showing fluctuating water levels at east end of Killin Wetlands and adjoining Spiering and Moore properties, 2002-2015.

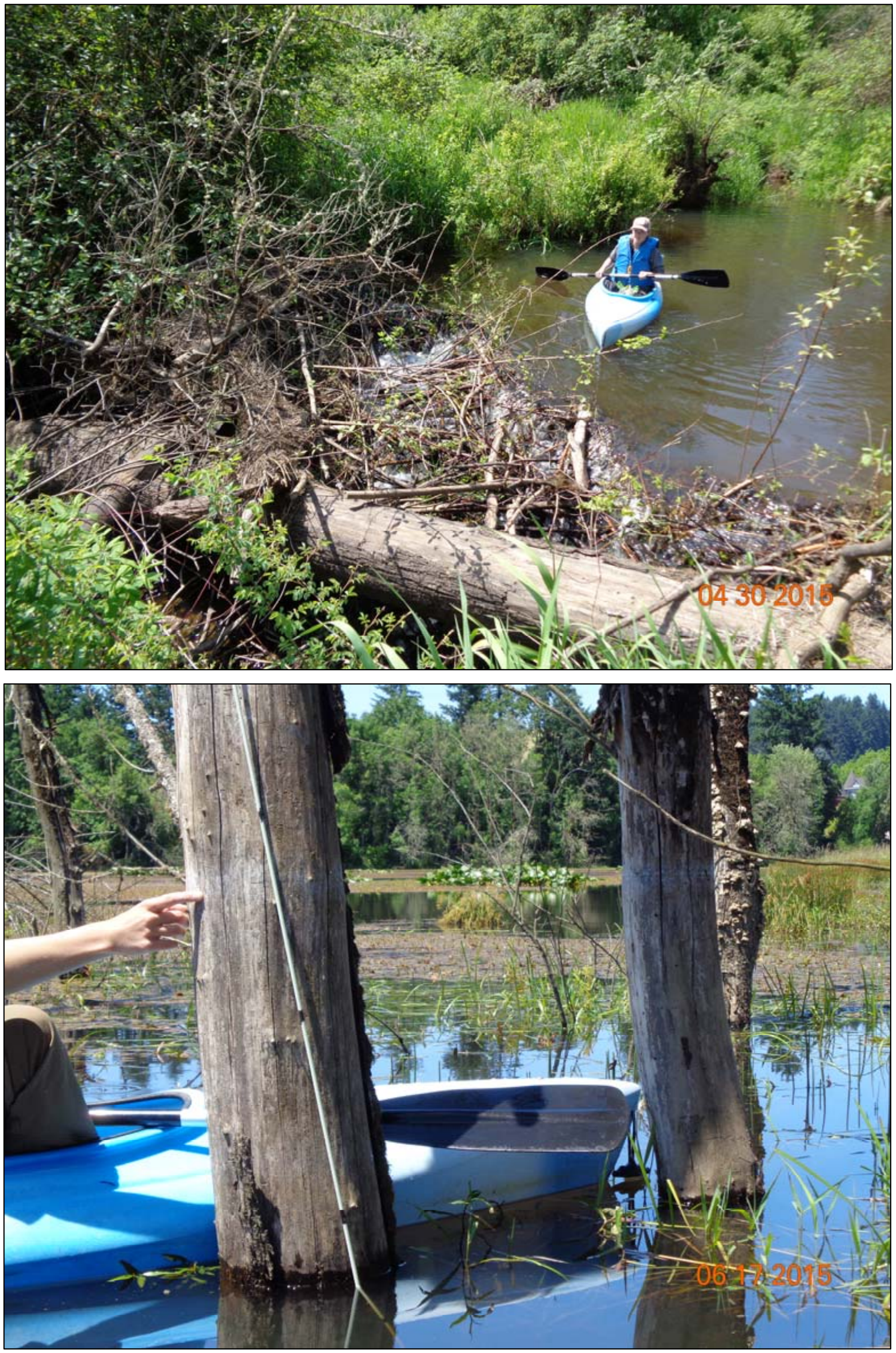


Figure 13. Killin Wetlands. Top: beaver dam at outlet of lake, 2015. Bottom: silt stains on dead ash trees, 2015. Photos by author.

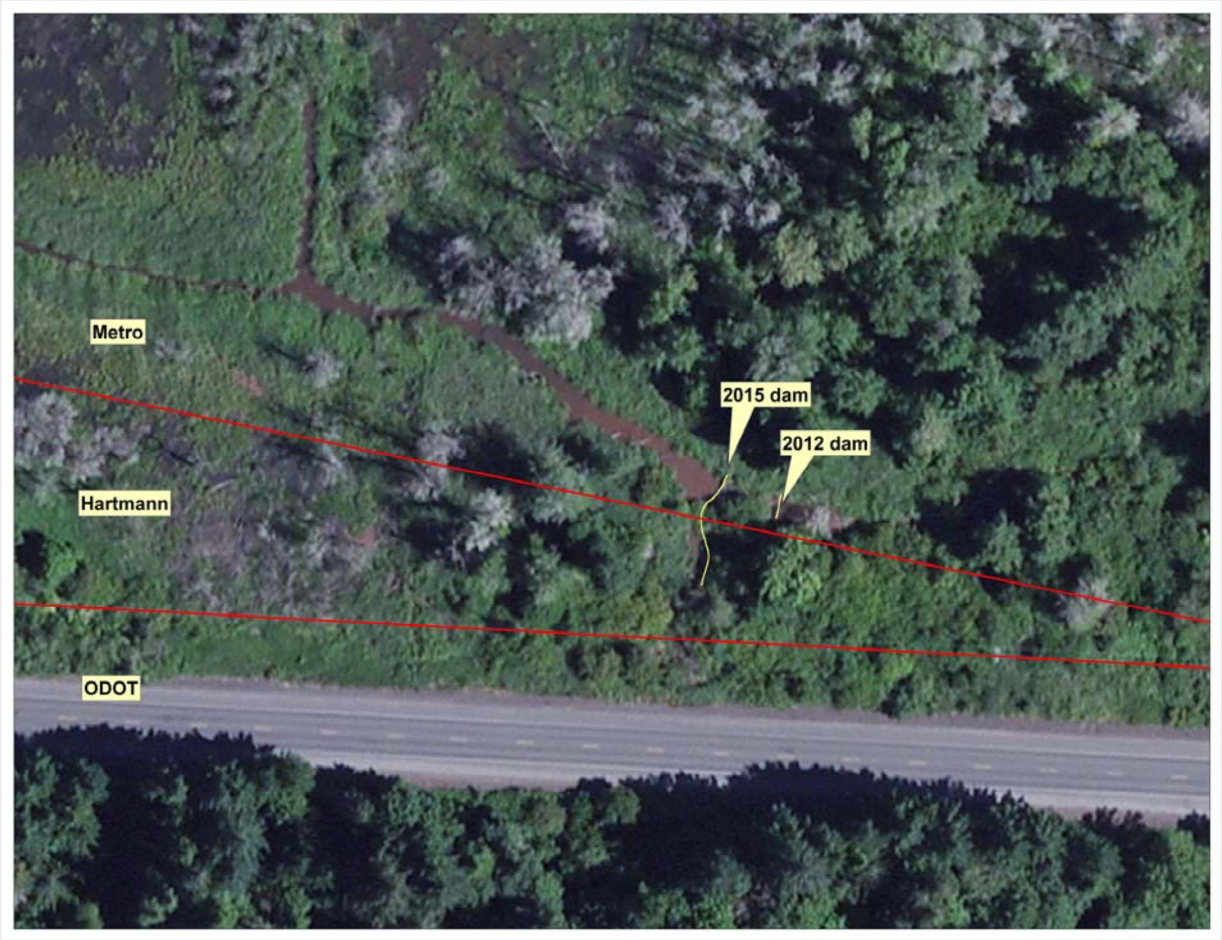


Figure 14. Locations of beaver dams at Killin Wetlands, 2012 and 2015. Note turbid water where beavers dredge mud from pool to place on dam. The existing dam is bisected by the property line between Metro and Hartmann.

Figure 15. Restoration of emergent marsh in former diked farmland, Upper Klamath Lake, Oregon. Areas of subsidence are visible clearly within the old dikes.

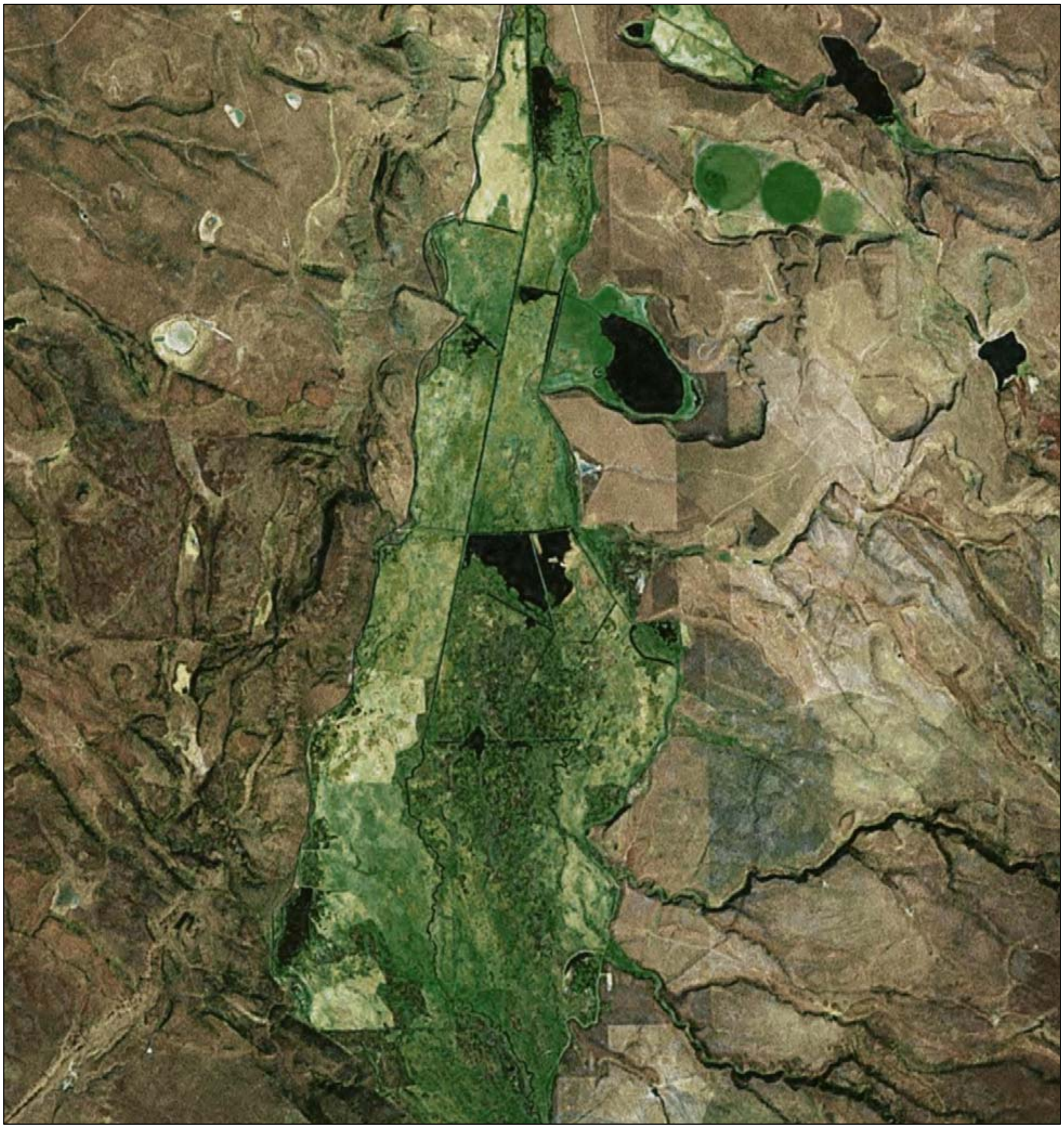


Figure 16. Crossdikes create stairstep patterns of wet to drier habitat within each cell, the wet containing native emergent marsh, the drier sites reed canary grass and creeping wildrye . Malheur National Wildlife Refuge.

Figure 17. Small-scale restoration on Labish soils, Coffee Lake (left), Lake Labish (right).

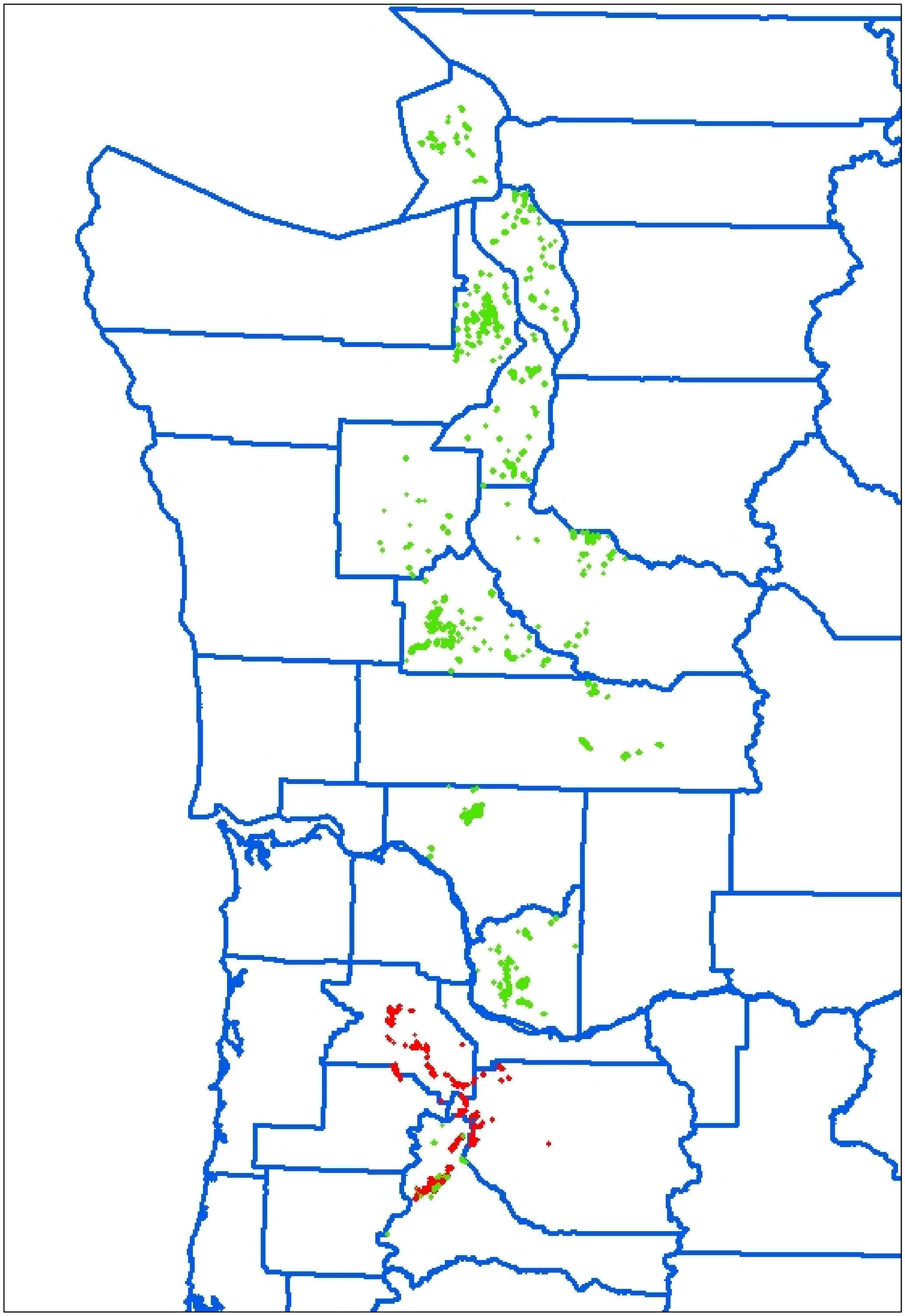


Figure 18. Distribution of Labish (red) and Semiahmoo (green) soils in Oregon and Washington.

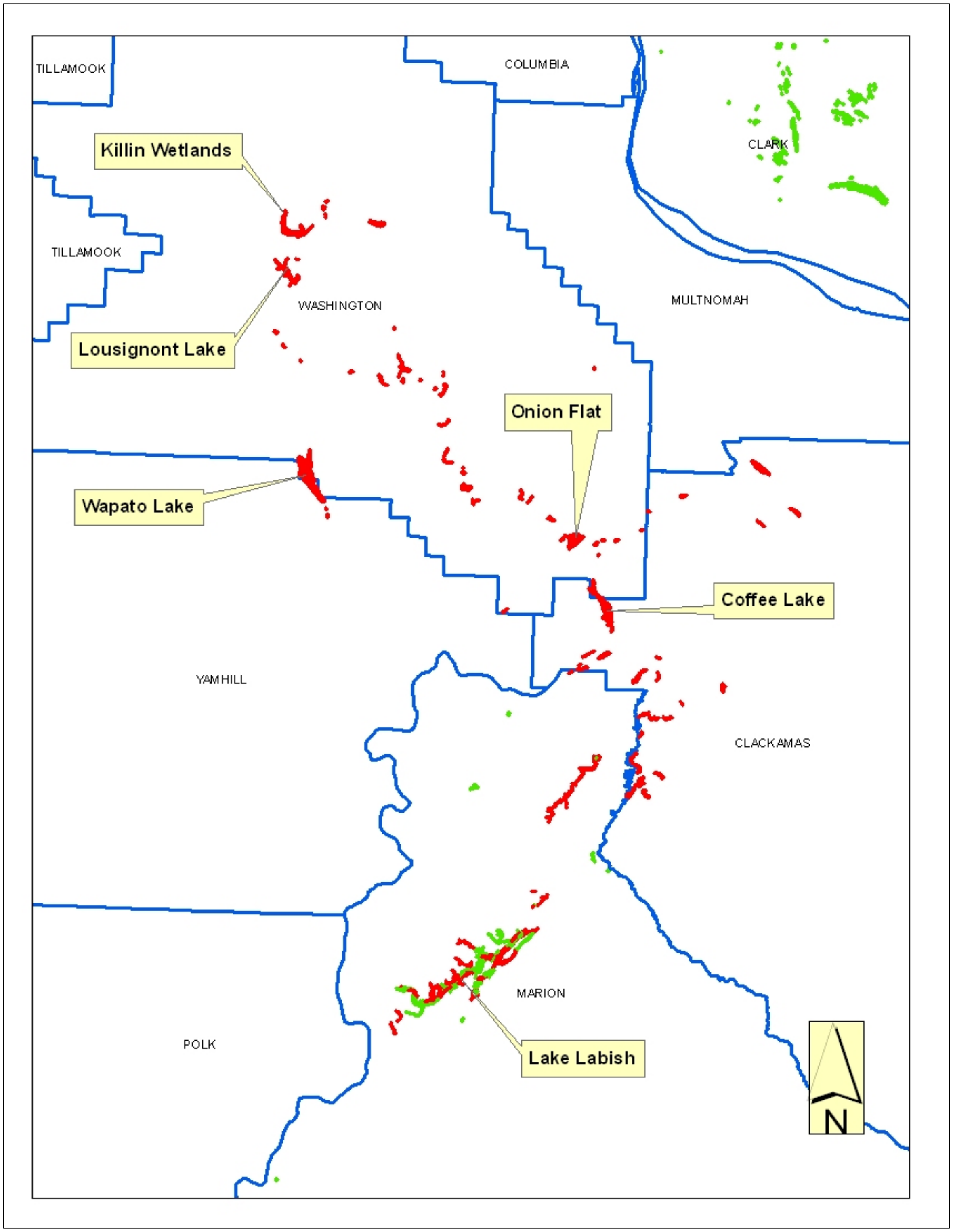
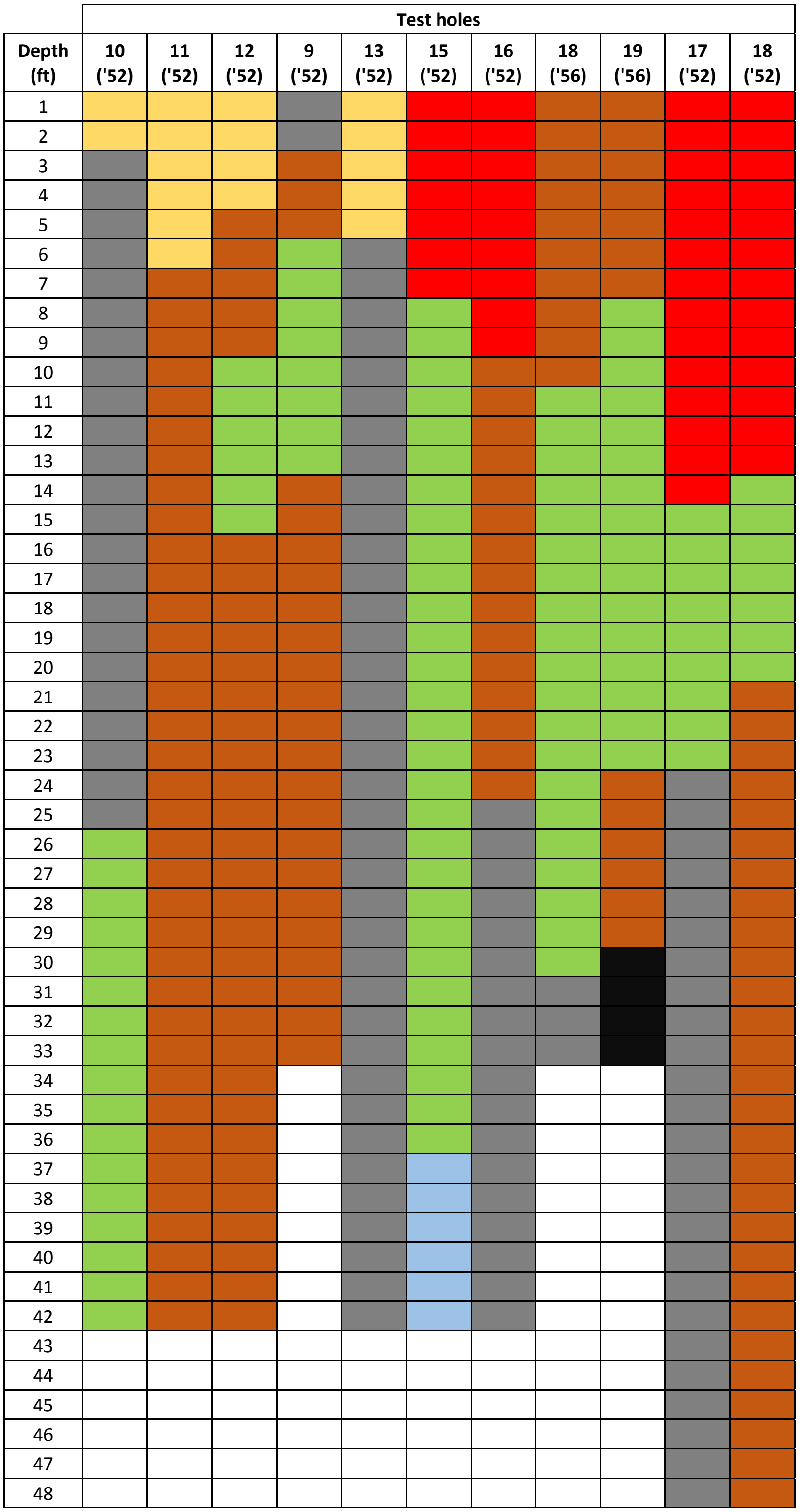


Figure 19. Primary historical wetlands in Oregon with Labish and Semiahmoo soils.



	Test holes										
Depth (ft)	10 ('52)	11 ('52)	12 ('52)	9 ('52)	13 ('52)	15 ('52)	16 ('52)	18 ('56)	19 ('56)	17 ('52)	18 ('52)
1	🟨	🟨	🟨	▨	🟨	🟥	🟥	🟫	🟫	🟥	🟥
2	🟨	🟨	🟨	▨	🟨	🟥	🟥	🟫	🟫	🟥	🟥
3	▨	🟨	🟨	🟫	🟨	🟥	🟥	🟫	🟫	🟥	🟥
4	▨	🟨	🟨	🟫	🟨	🟥	🟥	🟫	🟫	🟥	🟥
5	▨	🟨	🟫	🟫	🟨	🟥	🟥	🟫	🟫	🟥	🟥
6	▨	🟨	🟫	🟩	▨	🟥	🟥	🟫	🟫	🟥	🟥
7	▨	🟫	🟫	🟩	▨	🟥	🟥	🟫	🟫	🟥	🟥
8	▨	🟫	🟫	🟩	▨	🟩	🟥	🟫	🟩	🟥	🟥
9	▨	🟫	🟫	🟩	▨	🟩	🟥	🟫	🟩	🟥	🟥
10	▨	🟫	🟩	🟩	▨	🟩	🟫	🟫	🟩	🟥	🟥
11	▨	🟫	🟩	🟩	▨	🟩	🟫	🟩	🟩	🟥	🟥
12	▨	🟫	🟩	🟩	▨	🟩	🟫	🟩	🟩	🟥	🟥
13	▨	🟫	🟩	🟩	▨	🟩	🟫	🟩	🟩	🟥	🟥
14	▨	🟫	🟩	🟫	▨	🟩	🟫	🟩	🟩	🟥	🟩
15	▨	🟫	🟩	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
16	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
17	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
18	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
19	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
20	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟩
21	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟫
22	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟫
23	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟩	🟩	🟫
24	▨	🟫	🟫	🟫	▨	🟩	🟫	🟩	🟫	▨	🟫
25	▨	🟫	🟫	🟫	▨	🟩	▨	🟩	🟫	▨	🟫
26	🟩	🟫	🟫	🟫	▨	🟩	▨	🟩	🟫	▨	🟫
27	🟩	🟫	🟫	🟫	▨	🟩	▨	🟩	🟫	▨	🟫
28	🟩	🟫	🟫	🟫	▨	🟩	▨	🟩	🟫	▨	🟫
29	🟩	🟫	🟫	🟫	▨	🟩	▨	🟩	🟫	▨	🟫
30	🟩	🟫	🟫	🟫	▨	🟩	▨	🟩	⬛	▨	🟫
31	🟩	🟫	🟫	🟫	▨	🟩	▨	▨	⬛	▨	🟫
32	🟩	🟫	🟫	🟫	▨	🟩	▨	▨	⬛	▨	🟫
33	🟩	🟫	🟫	🟫	▨	🟩	▨	▨	⬛	▨	🟫
34	🟩	🟫	🟫		▨	🟩	▨			▨	🟫
35	🟩	🟫	🟫		▨	🟩	▨			▨	🟫
36	🟩	🟫	🟫		▨	🟩	▨			▨	🟫
37	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
38	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
39	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
40	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
41	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
42	🟩	🟫	🟫		▨	🟦	▨			▨	🟫
43										▨	🟫
44										▨	🟫
45										▨	🟫
46										▨	🟫
47										▨	🟫
48										▨	🟫

Figure 20. Simplified schematic profiles of ODOT boreholes along grade of former Gales Creek and Wilson River Railway through Killin Wetlands, for construction of Highway 6, 1952 and 1956. Green = organic soil; light brown = topsoil; dark brown = silt or silty clay; gray = clay; red = railroad fill; blue = water; black = shale. See Figure 7 for core locations.