Reprinted from 2001 *Columbia Basin Agricultural Research Annual Report. Spec. Rpt. 1026,* pp.84-95, 2001
Oregon State University in cooperation with USDA-Agricultural Research Service, Pendleton, OR

NO-TILL INFLUENCE ON HYDROLOGY AND STREAM MORPHOLOGY IN DRYLAND CROP AREAS

John D. Williams and Stewart B. Wuest

Introduction

East of the Cascade Mountains and to the south and east of the Columbia River, the Columbia Plateau grades from Sagebrush Shrub-Steppe into the Palouse, an area of nearly 64.5 million ha in Oregon, Washington, and British Columbia (Bloom 1978, Sims 1988, West 1988). Approximately 7.8 million ha in Idaho, Oregon, and Washington are now in dryland cropping systems, predominately producing wheat. The conversion to croplands triggered obvious and some not-so-obvious changes in small watershed hydrology and stream morphology. As a result of economic pressures, new technologies, and environmental regulatory pressure, farming practices appear to be changing more rapidly now than at any time in the last 30 years. Many of these changes are expected to produce positive environmental effects, but as in the case of changes resulting from conversion to croplands, not all of the changes will be expected, obvious, or rapid. We examine four aspects of this region's small watershed hydrology and stream morphology: (1) geomorphic conditions, (2) general human impact, (3) dryland agricultural practices, and (4) potential changes resulting from eliminating tillage in dryland farming.

Geomorphology

The soils and stream systems of this region developed on a landscape defined by basalt flows of the Miocene, episodic Pliocene floods from Lake Missoula, and loess and volcanic ash deposits during the last 1 to 2 million years (Busacca et al. 1985), the most recent of which occurred during the last 13,000 years (West 1988). Throughout this developmental period, the Cascade Mountains have cast a rain shadow across the interior intermountain region of the Columbia River watershed. Low annual rainfall on the western edge and central portions of this region, where flood deposits would have been abundant, has been sufficient to establish only marginal stabilizing vegetative cover. Prevailing west winds distributed the soil deposits across the plateau to the foothills of the Blue and Bitterroot mountain ranges. East of the flood deposits, with increasing elevation, precipitation, and vegetation, loess depth increased with development of steep slopes, up to 45 percent leeward. Judging by the persistence of these slopes to the present, the concomitant development of vegetative cover was sufficient to limit overland flow and water-caused erosion.

Drainage networks and riparian corridors developed in this mosaic of shrub-steppe and bunch-grass prairie, generally following folds or structural fractures in the underlying basalt. First- and second-order streams originate in both the Blue Mountains and within the cropland area of the plateau. On the plateau, the riparian communities appear to have been composed of halophytes or willow or cottonwood galleries, judging from current soil characteristics and relic vegetation stands. As evidenced by the development and persistence of steep slopes, the hydrologic response of streams originating on the plateau would have been slow and fed by shallow groundwater and deeper subsurface flow. Depending on the annual precipitation, headwater elevation, and presence or absence of mountain-fed springs, a mix of low-flow perennial and intermittent streams probably flowed through wet meadows.

Mt. Mazama ash in toe slopes indicates that the stream bottoms are sites of considerable colluvial deposition, but the presence of this material in large pockets of several cubic meters suggests that once it accumulated, it was not subject to significant stream erosion. We suggest that storm flows originating from within the prairie would have been slow in reshaping stream channels. Storm flow originating in the mountains, with sufficient force to carry and deposit large woody debris to the upper floodplain in the prairie, would have resulted in side-to-side shifts within valleys opening onto the plateau. Dense vegetation in the bottomlands of the prairies would have further dampened the energy from flows originating in the higher, forested areas.

Concomitant with geophysical influences, beaver (*Castor canadensis*) and fire influence on hydrology and stream channel development would have been direct and indirect. Beaver, believed to have been abundant throughout North America, would have directly influenced channel development through structure and side channel development and indirectly through manipulation of riparian plant communities (Naiman et al. 1988). The influence on small watershed hydrology would have been to reduce peak flows and potentially extend the available water for spring and early summer flows. Fire, resulting from lightning, likely created a shifting mosaic in the prairie and shrub-steppe, and in all but the most extreme cases would not have consumed riparian vegetation. The hydrologic effect from these fires would have been localized, short-lived (1 year), and probably without major influence on third-order stream hydrology.

Human Influence

Evidence of humans on the Columbia Plateau dates 15,000 years before present (bp) (Aikens 1993). The evidence corresponds to the last of the Missoula floods, ~ 13,000 bp, and the latest epoch of loess deposits, ~10,000 bp, when plants and soil conditions could provide sufficient habitat for human occupation. Fires purposefully set to manipulate vegetation to enhance game availability are likely to have had the same affect as wildfire, lacking any evidence of planned, systematic management. Early population numbers are unknown, and thus the full extent of human impact remains an open question. In the 1790's horses arrived on the plateau and, lacking any evidence of large grazing animals for at least 11,000 bp (Aikens 1993), they had the potential of initiating the first human-related changes to the region's hydrology. Concentrations of horses probably began having localized impacts on riparian areas shortly after arriving in the region, and had some impact on upland hydrology through grazing and soil compaction. Alternatively, the animals could have been dispersed, and thick riparian vegetation might have limited extensive access to streams, reducing the biological or geophysical impact.

In the early 1800's, the British government, through the Hudson Bay Co., pursued a policy of beaver extirpation south to the 40^{th} parallel (Simpson 1825). This policy was expected to halt the westward expansion in the United States, completely misinterpreting U.S. citizenry's desire to own land. By the time the first influx of settlers began arriving in the 1840's, the beaver population had been essentially eliminated within the interior Columbia River watershed. An abundance of failing structures (beaver dams) and nutrient-rich valley bottoms, composed of wetlands and wet meadows, would have buffered the initial impact on the regional hydrology, and stream structure and function.

Landuse changes in the last 200 years came rapidly, beginning with European livestock (cattle, sheep, and draft animals). These animals were mainly pastured in the bottomlands of many of the second- and third-order streams throughout the region. A combination of U.S. Government land settlement policies and extremely large numbers of sheep moving into and through the region in the late 1800's through the end of WWI resulted in overgrazing and cultivation of land unsuitable for crop production (Stoddart et al. 1975). Well into the 1930's teams of mules, oxen, or horses were used to cultivate cropland on the Columbia Plateau and Palouse. Slopes cultivated using animals were much steeper than slopes eventually farmed by machinery.

Fire is a common tool of agriculture and is used to "clean-up" fields in preparation for seeding. The predominant crop grown in this region, soft white wheat, is noted for abundant stem production. This material becomes an impediment to most tillage equipment with the possible exception of the moldboard plow. Less intensive tillage implements and direct-seed drills can roll the residue into a ball, which lifts the equipment out of the ground, frustrating the farmers' efforts. Crop residue also serves as a refuge for pathogens, weed seed, and emergent weed seedlings. Fire has been used as an effective tool for decreasing these problems.

Finally, stream channelization occurred with settlement of the Columbia Plateau. Channels have been regularly cleaned of vegetation to facilitate the efficient removal of water and soil from adjacent roads and fields. They have also been straightened. These practices, although unlikely to be applied today, remain in the USDA-National Resources Conservation Service Administrative Manual – Field Office Technical Guide (Sec. 4 Standards and Specifications, practices 326 and 580). Necessary to the development of agriculture is an efficient transportation network, which plays an important role in the surface hydrology of the Columbia Plateau and Palouse. Railroads constructed between 1890 and 1930 to haul wheat were located in the third- and fourth-order stream bottoms. This resulted in an early straightening of these waterways. Haul tracks used by wagons to transport wheat to railheads were developed along property lines, typically section lines. These roads became the current network of county roads, which are routinely graded and the barrow ditches cleaned of sediment and vegetation.

We assume that because of the extensive nature of dryland farming and the continued use of traditional farming practices, agriculture has changed the hydrology of the plateau. Controlled predominately by climatological conditions, the quantity of water available for stream flow has not been affected by agriculture. However, storm and annual hydrographs have undoubtedly changed. Overland flow has increased with agriculture, as evidenced by topsoil losses exceeding accumulation rates (Busacca et al. 1985). Zuzel et al. (1982), and Zuzel and Pikul (1987) reviewed 50 years of meteorological records and found that soil freeze-thaw events occurred up to 7 times per year, with a median of three on the

Columbia Plateau, and an increasing number to the north and onto the higher elevation Palouse. In these events, the soil profile freezes to depths of 30 cm on the plateau and deeper on the Palouse, but only approximately 50 percent of the events result in runoff and soil erosion (Zuzel 1994). The runoff that results from these events in agricultural fields is rapid and conveyed through the road barrow ditches directly to natural points of concentration, thus reducing the time to concentration and increasing storm hydrographs. Recently, we have recorded runoff events that are exceptions to the commonly held belief that only freeze-thaw events lead to overland flow. During the 1999-2000 crop year, we recorded only one freeze-thaw runoff event, but recorded 15 overland flow events from large plots located at the Pendleton agricultural research center. These plots have gentle slopes (2-6 percent) and overland flow accounted for 1 percent of annual precipitation. McCool et al. (1999) reported annual overland flow-to-precipitation values ranging from 3.0 to 22.9 percent, measured under various cropping practices over a 13-year period on the Palouse (Table 1). Individual overland flow-to-precipitation ratios ranged from 20 to 30 percent for individual storms in Pendleton. It might be safe to assume that overland flow expressed as a percent of rainfall increases across the plateau toward the steeper sloped, colder, higher elevation croplands of the Palouse.

Less infiltration into the soil means less soil moisture and, thus, less water available for subsurface flow. Depending where on the plateau or Palouse a wheat crop is growing, potential transpiration is 1.25 to 3 times the total annual rainfall. Storage of winter rainfall may be as low as 10-50 percent (Hammel 1996), depending on soil depth and crop rotation. Crop yields are closely tied to rainfall during March through June, when the probability of runoff is low. From March to harvest in August, wheat will use all available soil water to 1.5 m. Only infiltrated winter precipitation in excess of storage capacity would then be available to contribute to subsurface flow. The magnitude of this component of the water balance has only been estimated but it is generally believed that it is not large enough to contribute to stream flow into early summer during most years.

Table 1. Annual ratio of runoff to precipitation from a 13-year plot study of various tillage and cropping practices conducted on the Palouse in 264.8-mm average rainfall, near Pullman, Washington (McCool et al. 1999).

Treatment	Runoff/precipitation (percent)
Continuous bare fallow, tilled	44.0
Winter wheat/summer fallow, tilled	22.9
Winter wheat/spring peas, combination till and no-till	12.4
Winter wheat/winter or spring wheat, tilled	8.6
Winter wheat/winter wheat, direct seed	5.2
Winter wheat, rough tilled by chisel or moldboard plows	3.0

Regional changes in stream morphology are reflected in, and contribute to, hydrologic changes. Streams straightened and mechanically cleaned on a regular basis provide efficient conduits for overland flow, and medium flows concentrated in the channel have energy enough to scour sediment moved and deposited during low flows. This process has resulted in stream channels vertically disconnected from pre-agricultural flood plains by as much as 2 m (Williams et al. 2000). Most of these streams are not gauged. Attempts to determine 1.5-year dominant discharge (Combs et al. 1989) flows from morphological features (e.g., Williams et al. 1998) have resulted in underestimations of flow frequencies. Calculations, for instance, on the Umatilla River, a fourth-order tributary of the Columbia River, indicate that channel-forming flows occur as frequently as 1.2 to 1.4 years (C. Clifton, U.S. Forest Service Hydrologist, personal communication). In the last winter, classified as mild, we observed five flows exceeding the estimated 1.5-year stage on Wildhorse Creek, a 50,000-ha (192-mi^2) third-order stream, 95 percent of which is cropland on the plateau below the Blue Mountains. Since 1996, much of the region has experienced three 100-year rainfall events that resulted in truly bankfull flows, causing numerous bank failures from the over-steep banks of the incised channel.

Dryland Agricultural Practices

Changes that have occurred in agricultural watersheds are enormous and the factors influencing the watershed hydrology and stream morphology are numerous. But now agriculture in the United States is at a turning point and factors are converging to induce a change in traditional farming practices. Societal concerns about water quality and aquatic habitat are bringing social pressure to bear on landowner practices that cause water quality degradation. Recent news releases by the National Marine Fisheries Service indicate that much of the regulatory enforcement is going to be left to third-party lawsuits (http:/www public record sites in References). If so, citizens with standing can be expected to file suit directly against persons or businesses believed to be contributing to the impairment of habitat and decline of endangered fish species. The cost alone of fighting such a legal battle could easily exceed the resources of many farmers (Dr. Clinton Reeder, economist and farmer, personal communication). Increasing petrochemical (fuel, chemical, and fertilizer) costs are shaving the profit margin and creating economic incentives to reduce the number of times a farmer drags tillage equipment through the soil. In addition to the looming threat to agriculture by third-party lawsuits, some traditional farming practices have intrinsic weaknesses that threaten long-term productivity, and thus economic sustainability of such farming operations (Rasmussen et al. 1998).

Until the passage of Public Law 104-127(aka Freedom to Farm or FAIR), the predominant farming practice on the Columbia Plateau and much of the Palouse was the winter wheat/summer fallow rotation. It is still used on 1.8 million ha in the dryer portion of the region, where rainfall is considered inadequate to produce a crop every year. In this system, after a crop is harvested in August, another crop is not planted for 12 to 14 months. Generally, the field is plowed with a moldboard plow, disc, or chisel plow the spring following harvest. There are variations; occasionally the field is plowed and left rough following harvest, and not worked again until spring. Crop residue might be left standing, cut, bailed, and removed, cut and left on the ground, or burned (fall or spring). During spring the soil is cultivated and then worked from 1 to 4 times with a rodweeder (cultivator blades in combination with a square rod that turns counter to the direction of travel, dragged through the soil approximately 25-50 mm below the loose soil surface, which uproots weeds and seals the soil surface by creating a dust mulch, thus trapping soil moisture). This 2-year cropping system is used because it is the most economically secure option, particularly where annual rainfall is less than 330 mm. Unfortunately, it destroys soil organic carbon and impairs infiltration, leading to increased overland flow and field erosion (Rasmussen et al. 1998, Williams and Douglas unpublished data). These conditions lead to depauperate soils, decreased productivity, and a negative feedback system of deterioration. After harvest in the 209-mm annual rainfall zone and winter wheat/summer fallow system, soil-water storage generally ranges between 50 and 70 percent of annual precipitation, but in the second year, following the summer fallow, only 10 to 50 percent (Hammel 1996). This lack of infiltration leads to the highest rates of erosion, up to 450 tons/ha, and also the highest overland-flow-to-precipitation ratios of any farming system used on the Columbia Plateau or Palouse (U.S. Department of Agriculture 1978, McCool et al.1999).

Annual cropping, planting into the same field every year, is limited by cultural inertia, limited rainfall and soil moisture, the perception of reduced yields, and weed and disease problems. Annual cropping has the potential to reduce soil loss and, by implication, overland flow when it replaces the summer fallow system. McCool (unpublished data) reports that annual winter wheat in conventional farming systems is as efficient as no-till/burn systems for erosion control. If combined with an alternate (nonwheat) crop, and occasional spring planting, weeds and disease can possibly be controlled. Alternative crops suffer from lack of markets and stable prices, they are difficult to grow, and yields have been inconsistent. We have preliminary evidence suggesting alternative crops, particularly broadleaf species, might enhance infiltration, thus reducing runoff. A number of farmers have experimented with combinations of these systems at the low rainfall end of the plateau, but to date there have not been enough successes to convince many of their neighbors to follow suit.

A few farmers are trying no-till systems. The basic premise of no-till is to reduce soil disturbance to an absolute minimum and limit the number of times equipment is pulled over or through the soil. The no-till drills disturb the soil to varying degrees. At the extreme, a farmer can reduce crop production operations to three passes: combined planting/ fertilizing, spraying herbicide, and harvest, reducing the number of trips across thousands of hectares from seven or more down to three. Adoption of no-till systems by most farmers on the Columbia Plateau is impeded by cultural inertia; cost of equipment, and uncertain crop yields resulting from weed and disease buildup and changes in soil moisture management. No-till farming creates conditions with annual potential evaporation losses during summer fallow of up to 80 mm, depending on temperature, wind, and surface cover (Hammel 1996). The impact on soil quality and hydrology, however, appears to be uniformly positive in all no-till systems (Dao 1993, Malinda 1995, Singh et al. 1996, McCool et al. 1999). The question to ask now is what impact would widespread adoption of this farming system have on small watershed hydrology and stream structure and function? To answer that question, we must make extrapolations from anecdotal observations and research using ring-infiltrometers, permeameters, erosion plots, and models developed from erosion plots, e.g., the Universal Soil Loss Equation (USLE).

Potential Changes

Because no-till systems destroy relatively little of the soil structure, they are the closest a farmer can come to mimicking the natural prairie, while still producing nonperennial crops, (especially if crop residue is not burned before planting). Increases in infiltration cited above are large enough to nearly, if not completely, eliminate overland flow from croplands on the Columbia Plateau and significantly reduce it from croplands in the Palouse. Anyone having observed this region during a freeze/thaw runoff event with barrow ditches full of chocolate-brown water and 2-m-deep channels full to field level might easily imagine the changes increased infiltration might have on the storm hydrograph. Anecdotal observations appear to confirm these expectations. During the winter of 1999-2000, we observed runoff events that were obviously flowing from winter wheat and bare fallow croplands, whereas there was no evidence of flow from two first-order watersheds (~20 ha), in which we were beginning no-till research. Furthermore, no overland flow was recorded from an instrumented 1.6-ha hillslope (25 percent slope) during the same winter when we recorded 15 overland flow events from 12, 0.05-ha research plots (total area of ~ 0.7 ha) in conventional tillage in winter wheat/summer fallow. The overland flow from these conventionally tilled plots crosses a 200-m field in a first-order channel that is in no-till annual winter wheat. None of the 15 events created flow sufficient to flow across the entire 200 m. Thus, we would expect, with regional conversion to no-till farming, peak discharge of storm hydrographs to be dampened, sediment delivery to streams reduced, and an increase in soil water available for subsurface flow contributing to base streamflow. We would also expect these changes in runoff to be reflected in changes in stream morphology (Fig. 1). Sediment budgets should change; upland contribution of soil would be decreased, instream energy would be decreased, allowing for increased vegetation development and trapping of instream sediment sorting, and streambank failures would be reduced.

We conducted a preliminary test of this hypothesis. The Oregon Water Resources Department (OWRD) installed a stream gauge in Wildhorse Creek near the confluence with the Umatilla River in December, 1998. We assumed, conservatively, that 40 percent of the watershed would be in winter wheat following summer fallow. Using OWRD data for the two major storms from the winter of 1998-1999, and the overland flow/precipitation ratio from Pendleton and Pullman data, we calculated the reduction that would have occurred had the water infiltrated and not contributed to the peak flows. The results were not what we expected. Instead of a dramatic decrease in the peak flows of these two storms, our calculations suggested very modest reductions in peak flow and stage height (Fig. 2). If these preliminary findings are confirmed, then storm water discharged from cropland is not the primary cause of flashy peak flows seen in Wildhorse watershed. Thus, stopping, or reducing, cropland contribution to storm flow will not be sufficient to reduce the energy that causes accelerated stream bank and channel bottom erosion. Based on these results, we believe that a much more detailed examination of the sources to stormflow by cropped ground under a variety of cropping systems, urban areas, barrow ditches, and the 5 percent of the watershed in forestland is warranted.

Conclusion

It would be unrealistic to imagine a return to preagriculture hydrology systems. However, new sensibilities are spreading through the population, both within and outside of the agricultural community. Change, in the form of active, willing adoption and through regulation, is taking place in these watersheds. The full range of practices that are changing, or are likely to change in the next 10 years, i.e., road and barrow ditch management, urban development, and forestry, cannot be addressed here. Changes in hydrology, stream morphology, and subsequently stream habitat will not result solely from any one of these factors; change of each factor will have an incremental impact.

Agricultural research has traditionally focused on small-scale processes, seldom considering off-farm impacts. Watershed-scale research on the Columbia Plateau, particularly in cropland, is in its infancy. In the coming years we will continue to develop our understanding of agricultural impact on the region's water resources. In the mean time, we must be conscious of letting our expectations substitute for quantified research results. Coats (2000) discussed the pervasiveness of myths in forest hydrology, and even coined the term hydromythology. We must be wary of the same phenomenon in agricultural hydrology and work to avoid the mistakes, missteps, and potentially damaging false hopes it causes.

References

Aikens, C.M. 1993. Archaeology in Oregon. BLM/OR/WA/ST-9316+8100, United States Department of the Interior, Bureau of Land Management, Portland OR. 302 pages.

Bloom, A.L. 1978. Geomorphology; as systematic analysis of Late Cenozoic landforms. Prentice-Hall, Inc., Englewood Cliffs, NJ. 510 pages.

Busacca, A.J., D.K. McCool, R.I. Papendick, and D.L. Young. 1985. Dynamic impacts of erosion processes on productivity of soils in the Palouse. Pages 152-167 in Proceedings of the National Symposium on Erosion and Soil Productivity, New Orleans LA. Publ. ASAE, St. Joseph, MI.

Coats, R. 2000. Forest hydromythology: C.W. Slaughter (editor). Proceedings of the Seventh Biennial Watershed Management Conference. Water Resources Center Report No. 98, University of California, Davis (1999). Stillwater Sciences, Berkeley CA.

Combs, P.G., D.S. Biedenharn, M.D. Harvey, and C.C. Watson. 1989. A design approach for providing channel stability in Loess Hill streams. Pages 983-990 *in* Proceedings of the Fourth International Symposium on River Sedimentation, Vol. I, China Ocean Press, Beijing, China.

Dao, T.H. 1993. Tillage and winter wheat residue management effects on water infiltration and shortage. Soil SciencSociety of America Journal 57(6) : 1586 - 1595.

Hammel, J.E. 1996. Water conservation practices for sustainable dryland farming systems in the Pacific Northwest. American Journal for Alternative Agriculture 11(2, 3):58-63.

http:// public record sites
http://www.ci.eugene.or.us/StandingCommMinutes/pcMinutes/pc000214.htm
http://www.conserver.org/afw/process/FOTG_EC_final_mtg_summary092700.shtml
http://www.tri-cityherald.com/dams/news/010801.html
http://www.columbian.com/06202000/clark_co/133953.html
http://www.salmoninfo.org/news/crimes.htm
http://www.foxnews.com/science/071300/fish_fnc.sml

Malinda D.K. 1995. Factors in conservation farming that reduce erosion. Australian Journal of Experimental Agriculture 35(7):969-978.

McCool, D.K., C.D. Pannkuk, K.E. Saxton, and P.K. Kalita. 1999. Winter runoff and erosion on northwestern USA cropland. International Journal of Sediment Resources (in press).

Naiman, R.J., C.A. Johnston, and J.C. Kelley. 1988. Alteration of North American streams by beaver. BioScience 38:753-762.

Rasmussen, P.E., K.W.T. Goulding, J.R. Brown, P.R. Grace, H. Janzen, and M. Korschens. 1998. Long-term agroecosystem experiments: assessing agricultural sustainability and global change. Science 282:893-896.

Sims, P.L. 1988. Grasslands. Pages 265-286 in M.B. Barbour and W.D. Billings (editors). North American Terrestrial Vegetation. Cambridge University Press, New York, NY.

Simpson, G. 1825. Letter to the Governor and Committee, March 10, 1825. Page xxvii in E.E. Rich (editor). The Letters of John McLoughlin; from Fort Vancouver to the Governor and Committee, First Series, 1825–38. The Champlain Society, Toronto, 1941.

Singh, B., D.S. Chanasyk, and W.B. McGill. 1996. Soil hydraulic properties of an Orthic Black Chernozem under long-term tillage and residue management. Canadian Journal of Soil Science 76(1):62-71.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management, Third Edition. McGraw-Hill Book Company, San Francisco CA. 532 pages.

U.S. Department of Agriculture. 1978. Palouse Cooperative River Basin Study. Soil Conservation Service, Forest Service, and Economics, Statistics, and Cooperative Service. U.S. Government Printing Office, Washington D.C. 182 pages.

West, N.E. 1988. Intermountain deserts, shrub steppes, and woodlands. Pages 209-230 in M.B. Barbour and W.D. Billings (editors). North American Terrestrial Vegetation, Cambridge University Press, New York, NY.

Williams, J.D., C.F. Clifton, J. Webster, and R.W. Rickman. 1998. Morphological description main stem of the Umatilla River for TMDL development and monitoring. Western Watersheds: Science, Sense, and Strategies – Western Watershed Management Council Seventh Biennial Conference. Watershed Management

Council, Oakland, CA/Northwest Watershed Research Center, USDA–ARS, Boise, ID.
Williams, J.D., J.O. Loiland, K.M. Camara, and H.B. Williams. 2000. North-central Oregon dryland crop riparian conservation project. In Proceedings of the International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds American Water Resources Association 2000 Summer Specialty Summer Conference, Portland OR. (in press).

Zuzel, J.F. 1994. Runoff and soil erosion phenomena in the dryland grain growing region of the Pacific Northwest, USA. Trends in Hydrology1:209-216.

Zuzel, J.F., R.R. Allmaras, and R. Greenwalt. 1982. Runoff and soil erosion on frozen soils in northeastern Oregon. Journal of Soil and Water Conservation 37(6):351-154.

Zuzel, J.F., and J.L. Pikul, Jr. 1987. Infiltration into a seasonally frozen agricultural soil. Journal of Soil and Water Conservation 42(6):447-450.

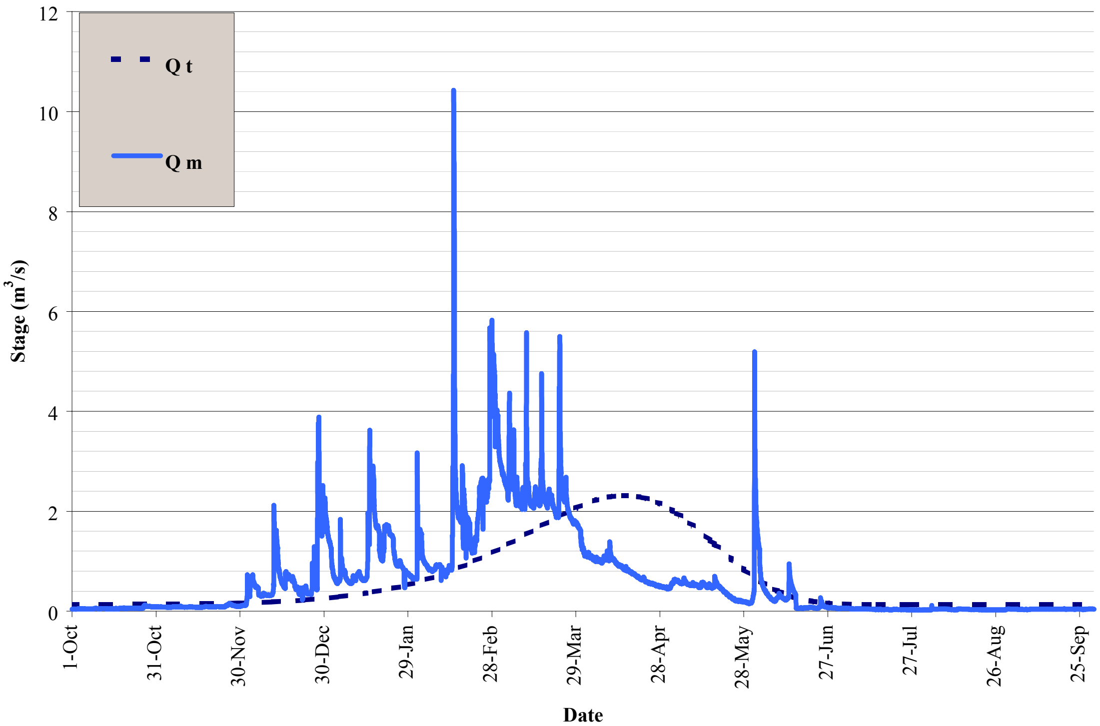

Figure 1. Expected changes in annual hydrograph resulting from increased infiltration and extended release through groundwater; a shift to late-season peak hydrograph and a damping of individual storm runoff events. Qt is theoretical and Qm is measured annual flow shown by stage height (flow depth) near the mouth of Wildhorse Creek, Oregon.

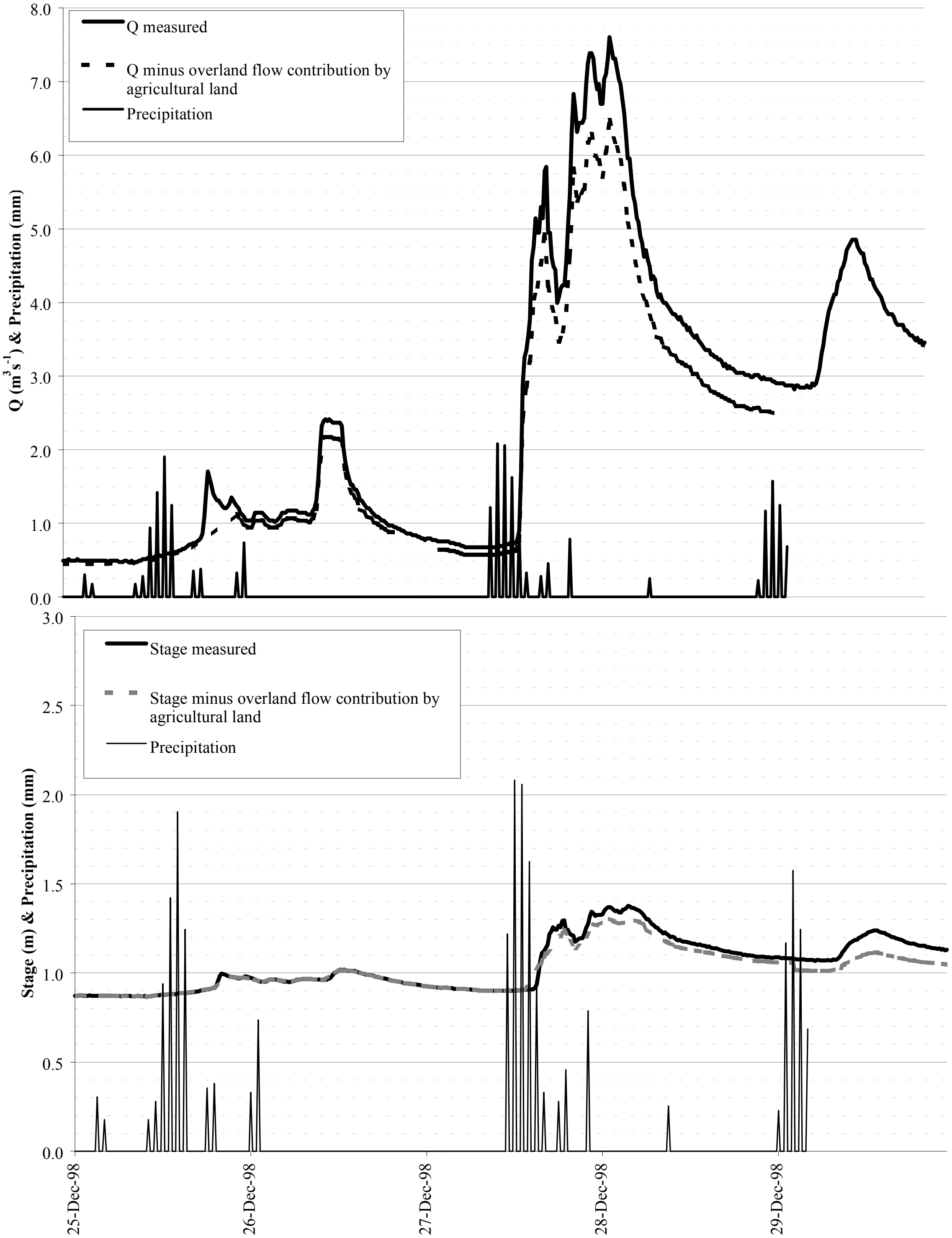

Figure 2. Storm flow from 25 and 27 December, 1998 rainfall on frozen soil events measured. Flow was measured in Wildhorse Creek, near Pendleton, Oregon. Estimated peak flow reductions were based on the assumption that without cropland in winter wheat following summer fallow, overland flow would not contribute to the storm hydrograph.