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Pacific Northwest National Laboratory
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Evaluation of the Potential for Agricultural Development at the Hanford Site

R. G. Evans
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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Executive Summary

By 2050, when cleanup of the Hanford Site is expected to be completed, large worldwide demands to increase the global production of animal/fish protein, food, and fiber are anticipated, despite advancements in crop breeding, genetic engineering, and other technologies. World population is projected to double to more than 12 billion people, straining already stressed worldwide agricultural resources. The current world surpluses in many commodities will not last when faced with increasing population, decreasing ocean fisheries, and rapid loss of productive lands from soil salination and erosion. The production of pharmaceuticals from bioengineered plants and animals will undoubtedly add more pressure on the already limited (and declining) arable land base. In addition, there will be pressure to produce crops that can help reduce the world's dependence on petroleum and be used for chemical plant feedstock.

These external, formidable pressures will necessitate increasing investments in irrigation infrastructures in many areas of the world to increase productivity. Intensive greenhouse culture and aquaculture also will be greatly expanded. There will be large economic and social pressures to expand production in areas such as the Pacific Northwest. Agricultural exports will continue to be important

The most likely large areas for expanded irrigation in the Pacific Northwest are the undeveloped East High areas of the Columbia Basin Project and non-restricted areas within the Hanford Site in south-central Washington State. Both of these are potentially highly productive areas for producing food and export capital. The environmental concerns will be large; however, the favorable growing conditions, high-quality (low-salinity) abundant water supplies and minimal problems with salination of soils make the Pacific Northwest a very desirable region for economically sustainable expansion from a world perspective.

The area known as the Hanford Site has all the components that favor successful irrigated farming. This semi-arid desert steppe area has deep soils, long summer days, a long growing season, good drainage, mild winters, and an abundant, high-quality, and dependable potential water supply from the Columbia River. Economically, the Hanford Site benefits from excellent transportation systems (roads, rail, and barge), extensive power systems, and the already well developed agricultural processing, supply, and service infrastructure that supports the regions agriculture.

Constraints to agricultural development of the Hanford Site are political and social, not economic or technical. Obtaining adequate water rights for any irrigated development will be a major issue.

Analysis of the land use data shows that the total irrigable area (not including buffer areas), including both the north (wildlife refuge areas) and south side of the river, is about 120,380 hectares (297,442 acres). Excluding the wildlife refuges, 6300 hectares (15576 acres) are classified for tree and vine crops, and 62,640 hectares (154775 acres) are classified for field crops. Over the entire site, not including buffer areas, 27,160 hectares (67116 acres) were classified as unsuitable for irrigation. One-kilometer-wide buffers were excluded from all rivers and lakes (20,100 hectares [49,681 acres]) and currently restricted areas (16,280 hectares [40239 acres]). State and federal wildlife reserves account for 35,740 hectares (88315 acres).

Potential land use and economic scenarios on the Hanford Site favor intensive, large-scale agricultural development growing high-value orchard, vineyard, and vegetable crops. Such large enterprises would be able to afford to import clean water and use high-level water management to minimize deep drainage. Irrigation technologies would be limited to highly efficient methods such as center pivots and microirrigation. Any suburban or small ranchette developments should be examined carefully in light of safety concerns and the associated generally poor levels of water management.

Numerous anticipated future advances in irrigation and resource conservation techniques will greatly minimize the negative environmental impacts of agricultural activities. These include precision agriculture techniques, improved irrigation systems, and controls. It is believed that such improved systems will be the norm for farming in 50 years.

Scientific irrigation scheduling and a network of supporting weather stations must be part of the total system for water and pest management of any future agricultural development on the Hanford Site. It is highly probable that any future irrigation development on the Hanford Site would be pressurized irrigation systems because of the site's very sandy soils and undulating topography. Water would be supplied to the fields by pressurized pipelines rather than canals or ditches. Because of the light soils and widely variable topography of new lands such as the Hanford Site, new advances in microirrigation and self-propelled irrigation (i.e., linear move and center pivot systems) will probably have the most promise for future irrigation.

A reasonable estimate of deep percolation in 50 years would be the current best achievable levels of the best technology: from 2% to 15% of the applied water, not including water applied for frost protection or other non-irrigation uses. Recharge from irrigation would probably range from 50 to 500 mm/yr compared to historical estimated natural recharge rates, even with the expected improved technologies and systems. Wine grapes would have the least recharge, while field crops would potentially have the greatest deep percolation losses. Small acreage, irrigated ranchette development would probably contribute about twice the recharge to the unconfined aquifer systems as large scale irrigation.

Acknowledgments

Pat Daly with the Franklin County Conservation District and Jeff Godfrey with the Grant County Conservation District by providing GIS files on agricultural land use in their counties. Ms. Cindy Mead and Tammy Killian did the land use mapping needs for this project. Mr. Chas Scripter with the USDA-NRCS in Spokane provided GIS soils maps and needed othrophotos for the analysis. Dr. Mary J. Hattendorf conducted the GIS analysis of the combined data sets. Dr. Charles Kincaid and Dr. Michael Fayer with PNNL provided valuable assistance by providing maps and documentation and thoughtful review.

Acronyms

AWC	available water holding capacity of a soil
BIA	Bureau of Indian Affairs
CBP	Columbia Basin Project (irrigation and power)
DEM	digital elevation maps
DOE	U.S. Department of Energy
DLG	digital line graphics
ET	evapotranspiration
ETr	reference evapotranspiration for alfalfa
GIS	geographic information system
GPS	global positioning system
LEPA	Low Energy Precision Application
LIGO	Laser Interferometer Gravitational-Wave Observatory
PAM	polyacrylamide formulation used to control soil erosion
PAWS	Public Agricultural Weather System
SIS	scientific irrigation scheduling
USBR	U.S. Bureau of Reclamation
USDA-ARS	U.S. Department of Agriculture - Agricultural Research Service
USDA-NRCS	U.S. Department of Agricultural-Natural Resource Conservation Service
USGS-EROS	U.S. Geological Survey - Earth Resources Observation Systems
WDOE	Washington Department of Ecology
WSU	Washington State University

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1.0 Introduction

In the early 1940s, the U.S. Department of Defense used the right of eminent domain to acquire about 1520 square kilometers (586 square miles) in Benton and Grant Counties of Washington State as part of the Manhattan Project to develop the atomic bomb. Until the late 1980s, the Hanford Site in south-central Washington continued to be involved in the production of weapons-grade fissionable materials (Figure 1.1). More recently, the primary mission of the Hanford Site has focused on the cleanup and disposal of hazardous waste and radioactive materials resulting from this previous industrial endeavor.

Cleanup efforts are estimated to be completed around 2050. A small fraction of the total Hanford Site will be reserved by the U.S. Department of Energy (DOE) for waste disposal and protection from residual radiation sources. The remainder of the land is anticipated to be declared as excess and gradually returned to other uses until all excess lands are returned at the end of the DOE mission. There are tremendous regional and national pressures to establish the future use of these excess lands.

A substantial portion of the Hanford Site is ideally suited to the type of high-value production agriculture currently practiced in the mid-Columbia region. Agricultural development of portions of this area could have a large impact in both regional and state economies, providing new employment opportunities and growth. Consequently, there are intense regional political and economic pressures to release at least some of these lands for agricultural uses.

On the other hand, the portion of the Columbia River flowing past the Hanford Site, known as the Hanford Reach, is the last section of the lower Columbia River unaffected by dams. In addition, the Hanford Site is part of the oldest and largest remaining old-growth desert ecology community in Eastern Washington. Thus, there are equally fierce proponents for protecting the Hanford Site from any future development and maintaining it as an ecologically sensitive reserve.

The DOE released the Hanford Site Comprehensive Land Use EIS (DOE 1999), which suggests future cropping patterns, agricultural land use, and associated water issues. This study and the information will be the basis for agricultural land use scenarios used to estimate risk and radiation dose to future inhabitants of the Hanford Site. These scenarios will become part of assessments conducted to evaluate remedial actions and disposal alternatives at the Hanford Site until the cleanup is completed within the next 50 years.

This particular study is not related to any existing DOE study of potential future land use. Likewise, this study does not consider existing proposals by the Benton County Planning Commission or other agencies, public, or private groups, or currently restricted non-industrial lands (i.e., the Arid Lands Ecology Reserve). Similarly, endangered species, biological diversity and wildlife management, global climate change, potential concerns by lending organizations to finance development, effect on utility systems, waste management and refuse disposal, waste water (septic tanks, livestock containment) treatment, hazardous waste management, public health concerns with hazardous waste and exposure, or the affects of agricultural development on specialized installations such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) were not part of this evaluation. The purpose of this report is

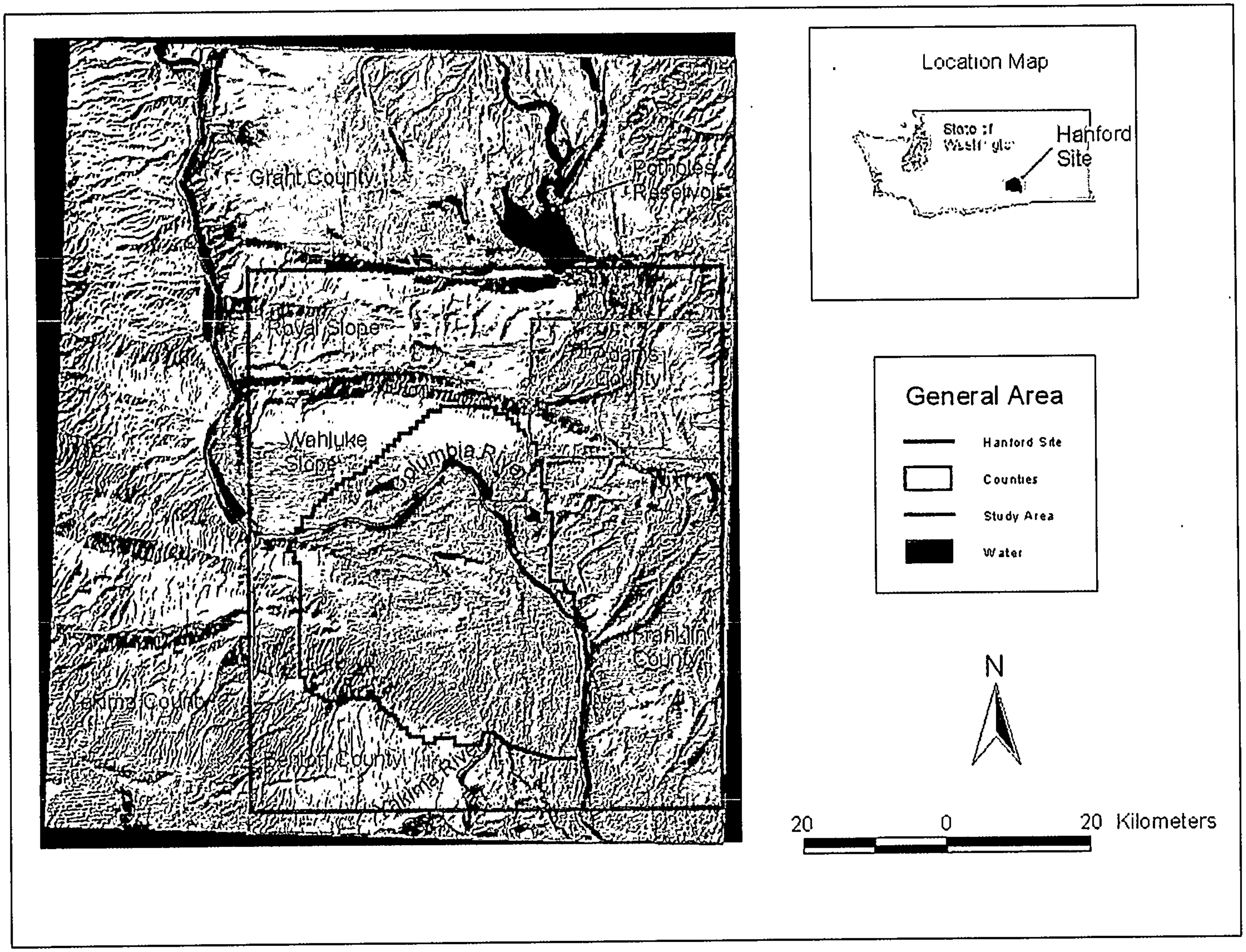

Figure 1.1. Map Showing the General Location of the Hanford Site and the Study Area

to suggest potential cropping patterns and related water requirements after closure of the Hanford Site in the event that some lands are opened to *irrigated* agricultural development. Potential future agricultural land uses were based on current irrigation and cultural practices that will continue to be improved and developed over the next 50 years. While there is some speculation, the intent is only to suggest reasonable future uses of Hanford lands in the event they become available for agricultural development based on *current* farming practices.

This is an attempt to characterize the attributes of the Hanford Site that are appropriate for agricultural development and determine the potential for future agricultural land use given current irrigation technology, crops, and crop rotation scenarios. It was assumed that development must be economically sustainable using current agricultural enterprises as a basis. Anticipated future advances in irrigation and resource conservation techniques, water rights issues, and impacts of possible shifts in agricultural production are discussed. Also examined are crop water use needs per unit area, potential advances in irrigation technology that would impact irrigation efficiencies, and issues of environmental stewardship.. Anticipated average irrigation rates and amounts for various crops and net infiltration rates (groundwater recharge) also are part of the analysis.

Rainfed or "dryland" agriculture was not included as part of this analysis because such operations might not be sustainable due to low annual precipitation and low commodity prices. The economics may change in the future, and these options should be re-evaluated at that time. A potential exists to use various areas of the Hanford Site for dryland livestock grazing or winter wheat production. However, these uses present challenges because of the large acreage requirements per animal, perceived incompatibility with various ecosystems, and the Hanford Site's lower natural precipitation relative to nearby lands where winter wheat is grown.

The analysis is based on comparison of the acreage and water requirements of the current farming community and trends in Franklin, Grant, and Adams counties. The year 1996 was used as the baseline because of the availability of orthoquad maps for that year and data from the 1997 Census of Agriculture. The lands used as the study area were approximately bounded on the north by the Frenchman Hills (Royal Slope), on the east by Highway 395, and on the south by the Yakima River.

One particular goal was to obtain estimates of the amount of deep percolation and recharge that might result from development of irrigated agriculture on the Hanford Site. Deep percolation (also called deep drainage) is defined as the amount of water from natural or artificial sources that travels downward through the soil profile until it is below the plant's root zone and unavailable for crop use. Deep percolation is generally the result of infiltrated water that exceeds the soil's ability to hold it. However, small channels and other established flow pathways in the soil can carry substantial amounts of water directly to the groundwater (preferential flow), effectively bypassing the plant rooting zone. Preferential flow exists in almost all soils and is a major factor in soil water movement, but it is generally neglected because it is difficult to measure.

Recharge, on the other hand, is the flux of water that arrives at the upper boundary of the unconfined aquifer (water table). Deep percolation and recharge are assumed to be equal in magnitude when integrated over many years, but temporal distribution will be different because of the transit time through the vadose zone towards the groundwater. Recharge can influence the elevation of the water table, but is generally viewed as a problem only when it carries excessive contaminants to the groundwater.

Existing data and geographic information system (GIS) software (ArcView) were used to make maps of soils and topography and to summarize 1996 crop use of the current irrigated lands surrounding the Hanford Site. These data were compared to soil and topographic conditions at the Hanford Site to assess suitability and/or limitations for various crop and irrigation system scenarios. All lands currently within the Hanford Site, except for disposal sites such as the central plateau (200 East and West Areas) and other industrialized sites that might be restricted in the future, were considered for their potential for agricultural development regardless of their current status.

2.0 Environmental Setting

This section briefly describes the physical and environmental setting of the Hanford Site to set the stage for the discussion on agriculture. Hanford Site geology, soils, topography, climate, potential evapotranspiration, recharge rates, and water resources (surface and subsurface) are discussed.

2.1 Geology

The geology and hydrology of the Hanford Site have been studied extensively over the past 50 years (Cole et al. 1997; Neitzel et al. 1997). Geologically, the Hanford Site lies within the Pasco Basin, a large structural depression that has collected a relatively thick sequence of fluvial, lacustrine, and glacio-fluvial sediments over the past several thousand years. The Pasco Basin and nearby anticlines and synclines are underlain by or composed of the Columbia River Basalt Group, a sequence of continental flood basalts covering more than 163,000 km^2 (63,000 mi^2) in Washington, Oregon, and Idaho that occurred over a period from 17 million to 6 million years ago.

Landslides have occurred along the northern portions of the Yakima Ridge folds of the Pasco Basin along basalt and sedimentary interfaces. They have also occurred along steep river embankments (i.e., White Bluffs) to the east of the Hanford Site and are primarily due to subsurface irrigation return flows that have saturated lower portions of the embankments, resulting in slumping.

The underlying basalt layers are often fractured, and numerous geologic faults run through the Hanford Site. The basalt flows are frequently separated by interbeds of epiclastic and volcaniclastic sedimentary layers and old residual soils. Overlying the basalts are fluvial and lacustrine sediments of the Ringold formation and the glacio-fluvial Hanford formation.

The sediments in the Hanford formation are primarily the result of cataclysmic flooding due to the periodic breaching of ice dams in western Montana and northern Idaho that caused huge volumes of water to spill across eastern and central Washington. These floods are among the largest ever documented anywhere in the world, the last of which occurred about 13,000 years ago. These sediments were channeled and alluvium was deposited between flood events. Later aeolian depositions of glacial till cover portions of the site. Recently, the sediments have been locally reworked by winds, and sand dunes are common in southern and eastern portions of the Hanford Site.

2.2 Soils

Hajek (1966) described 15 different general surface soil types on the Hanford Site, ranging from sand to silty and sandy loams. These same soils are found elsewhere in Benton, Grant, Adams, and Franklin counties, and most are being irrigated. Figure 2.1 shows the distribution of major soil types in the study area and the Hanford Site. As can be seen, the major agricultural soil types in the surrounding area are loamy sands, sandy loams, fine sandy loams, silt loams, and sands, all of which are common on the Hanford Site. These soils are characterized by relatively high infiltration rates, low water holding

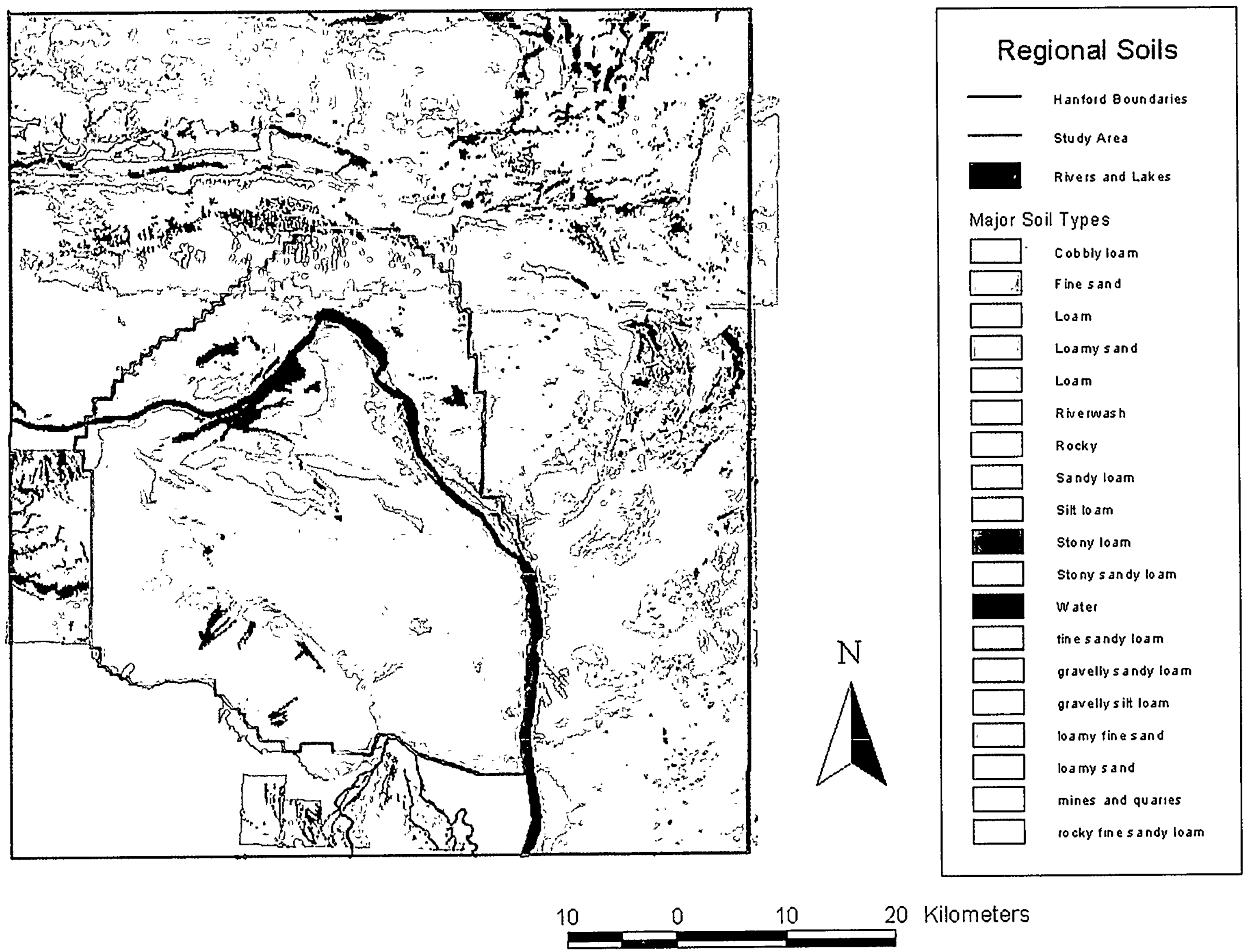

Figure 2.1. General Soils Map of the Study Area and the Hanford Site

capacities, and very low clay and organic matter contents. They are easily eroded by wind and water. Probable ranges of infiltration rates and available water holding capacity (AWC) for each soil type, based on texture from soil survey information, are presented in Table 2.1.

2.3 Topography

The Hanford Site occupies an area roughly 50 km (N-S) by 40 km (E-W) that is about 1517 km^2 (586 mi^2) in south-central Washington. It lies north of the confluence of the Yakima and Columbia Rivers. The Columbia River flows in an easterly direction across part of the northern boundary and, turning south, forms part of the eastern boundary of the Hanford Site. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundary. The Saddle Mountains lie to the north of the Hanford Site. Adjoining lands to the west, north, and east are principally range and commercial agricultural land. The cities of Richland, Kennewick, and Pasco (the Tri-Cities) and West Richland are located southeast of the site and constitute the nearest population centers.

About 1100 km^2 (427 mi^2) of the Hanford Site are in Benton County. The remainder lies in Grant County, north of the Columbia River, and although it is part of the site, is primarily managed by the National Fish and Wildlife Service and the State of Washington as wildlife refuges and recreation areas. A large portion of land (30,900 hectares [76,300 acres]) in the southwest portion of the site on the eastern side of Rattlesnake Mountain is currently set aside as the Fitzner-Eberhardt Arid Lands Ecology Reserve. Only about 6% (about 90 km^2 [33 mi^2]) of the total area has been disturbed and is used for the production of special nuclear materials and the storage and disposal of wastes.

Figure 2.2 is a graphical representation of the diverse and widely varying topography in the region around the Hanford Site. Elevations within the Hanford Site vary from about 120 m (400 ft) above mean sea level near the Columbia River to more than 1060 m (3480 ft) at the top of Rattlesnake Mountain at the southern end of the site. Wahatis Peak in the Saddle Mountains at the north end of the Hanford Site reaches almost 800 m (2500 ft). However, most of the site is relatively flat and similar to many of the irrigated agricultural lands in the region.

2.4 Climate

Annual precipitation on the Hanford Site is only about 160 mm (6.3 in.), and irrigation is required for economic production of most crops. Average Class A pan evaporation for the area is about 1400 mm (4.6 ft) for the growing season. Winds are generally from the northwest although considerable winds from the southwest occur in the spring and fall. The record maximum temperature is 45°C (113°F), and the record minimum temperature -31°C (-23°F). Additional information on climate on the Hanford Site is contained in Hoitink and Burke (1997).

Table 2.1. Range of Permeabilities and Available Water Holding Capacities (AWC) of Selected Soils

Soil	Soil Survey[a]	Permeability mm/hr		AWC[c] mm/mm		Bulk Density[b]	AWC[b,c] mm/m	
		Low	High	Low	High		Low	High
Ritzville Silt Loam (Ri)	BC/G	20.32	63.5	0.18	0.20			
Rupert Sand (Rp)	BC/G	127.00	254.0	0.10	0.12	1.52	58.3	666.7
Hezel Sand (He)	BC/G	127.00	254.0	0.10	0.12	1.60	66.7	83.3
Koehler Sand (Kf)	BC/G	127.00	254.0	0.09	0.11	1.48	33.3	50.0
Burbank Loamy Sand (Ba)	BC/G	>	254.0	0.07	0.09	1.50	41.7	50.0
Ephrata Sandy Loam (El)	G	50.80	152.4	0.13	0.16	1.70	208.3	241.7
Lickskillet Silt Loam (Ls)	BC/G	5.08	20.3	0.08	0.10			
Ephrata Stoney Loam (Eb)	G	50.80	152.4	0.10	0.13			
Kiona Silt Loam (Ki)	BC/G	20.32	63.5	0.08	0.10			
Warden Silt Loam (Wa)	BC/G	20.32	63.5	0.18	0.20	1.40	150.0	183.3
Scootney Silt Loam (Sc)	BC/G	20.32	63.5	0.18	0.20	1.40	158.3	166.7
Pasco Silt Loam (p)	BC/G	20.32	63.5	0.18	0.20			
Equatzel Silt Loam (Qn)	BC/G	20.32	63.5	0.18	0.20	1.52	241.7	291.7
River Wash (Rv)	BC/G	>	254.0	0.03	0.05			
Dune Sand (D)	BC/G	>	254.0	0.05	0.07			

(a) BC is Benton County Soil Survey (USDA- Soil Conservation Service 1971), G is the Grant Count Soil Survey (USDA - Soil Conservation Service 1984).
(b) Data are the ranges of values found by Hagood et al. 1970.
(c) AWC is available water holding capacity of soil or the amount of soil water available for crop use. AWC is the difference between measured values of field capacity and permanent wilting point.

2.5 Potential Evapotranspiration

Potential evapotranspiration (ET) is basically the maximum amount of water that will be used by a crop, depending on growth stage and climatic conditions. For simplicity, these calculations are usually made for a "reference" crop such as well watered alfalfa (ET_r) or grass (ET_o). Actual water use of a particular crop is adjusted by decimal values of "crop coefficients" that are multiplied times the reference evapotranspiration. The Penman equation (Penman 1948) as modified by Wright (1982) and Allen et al. (1989) was used to calculate the reference potential evapotranspiration (ET_r) for the area.

Climatic records for several weather stations in the irrigated agricultural areas near the Hanford Site were analyzed to determine potential crop water use, also called potential evapotranspiration. The Public Agricultural Weather System (PAWS) station operated by Washington State University (WSU) near Mattawa is probably the most representative agricultural weather station for expected Hanford Site conditions. The average alfalfa reference evapotranspiration (ET_r) for the April through October growing

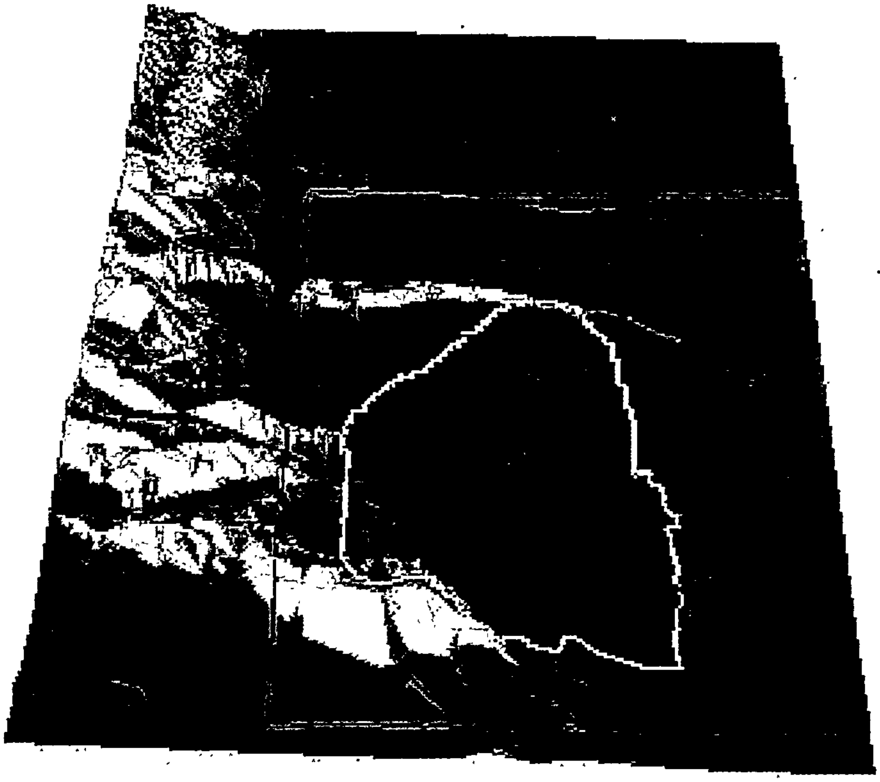

Figure 2.2. Three-Dimensional Map Showing Elevation Ranges for the Area Surrounding the Hanford Site (white line) and the Study Area (dark line) and the Columbia River in Central Washington

season is about 978 mm (38.5 in.) for all stations and 1060 mm (41.7 in.) for Mattawa. Figure 2.3 is a graph of the long-term average alfalfa ET_r for several PAWS weather stations around the Hanford Site, with the peak water use of about 225 mm (8.9 in) occurring in July. Crop water use can vary substantially from year to year depending on climatic conditions. Table 2.2 is a listing of the long-term average crop water use over the season from stored soil water (winter precipitation) and irrigation. Deficit irrigation or other management practices may reduce these values.

2.6 Recharge Rates

Determining recharge rates is critical to the long-term environmental cleanup efforts and management at the Hanford Site to ensure long-term protection of groundwater from industrial wastes. Gee et al. (1992) estimated that the time required for contaminants to travel through the thick unsaturated zone at the Hanford Site ranged from thousands of years, for recharge rates below 1 mm/yr, to tens of years for recharge rates above 50 mm/yr.

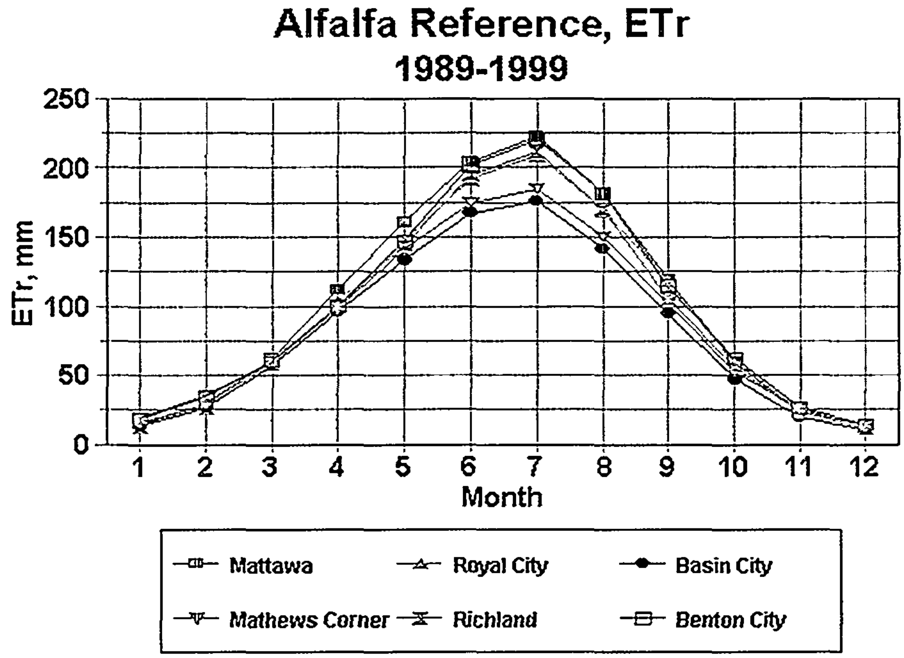

Figure 2.3. Annual Distribution of Potential Evapotranspiration of Alfalfa (ETr) for PAWS Weather Stations in Irrigated Agricultural Areas Near Hanford for 1989-1999

Currently, most of the recharge is from natural precipitation, although significantly higher recharge rates are estimated due to localized industrial activities (i.e., central plateau operational areas). Some artificial recharge to the Hanford Site that results from private irrigation development (from deep wells) lies to the north of the Site in the Cold Creek drainage. This amount is estimated to be small because the irrigation systems are efficient and the high cost of pumping water encourages good management. Estimated recharge from any future irrigated agriculture development on the Hanford Site will likewise depend on the types of irrigation systems used and their management.

The wide discrepancies in estimated recharge rates for the Hanford Site are attributed to variations in precipitation, vegetative cover, and surface soil textures. Gephart et al. (1979) analyzed data from long-term field studies at the Hanford Site and concluded that recharge from natural precipitation through thick unsaturated sections is almost negligible. Gee et al. (1992), using lysimeter data collected at a number of locations on the Hanford Site over a period of 20 years, found that recharge rates ranged from more than 100 mm/yr to rates near zero (i.e., no measurable drainage). Coarse-textured soils without plants yielded the most recharge, and fine-textured soils with or without plants yielded the least. Deep-rooted plants, such as sagebrush, were generally successful in limiting recharge on all soils on the Hanford Site to near-zero amounts, but shallow-rooted plants such as cheatgrass appeared unable to prevent recharge. Subsurface drainage (i.e., recharge) from a cheatgrass-covered lysimeter averaged about 35% of the total annual precipitation during a 3-year test (1984 to 1986). Fayer and Walters (1995) estimated that annual recharge for the non-industrial areas of the Hanford Site typically averaged less than 10 mm/yr (i.e., "background recharge rates").

Table 2.2. Long-Term Average Crop Water Use in mm per Year at Various PAWS Weather Stations Near the Hanford Site

Crop	Mattawa	Royal City	Basin City	Mathews Corner	Richland	Benton City	Pasco
Penman Alfalfa[a]	1441.1	1355.6	1184.1	1258.1	1357.4	1417.2	1384.9
Alfalfa	1140.1	1071.6	927.1	979.8	1067.6	1116.4	1097.3
Asparagus	869.3	819.4	702.6	745.0	811.1	852.0	836.7
Carrots	599.7	560.9	484.2	508.2	564.9	585.7	582.7
Grain Corn	816.6	763.0	655.3	688.0	764.7	798.0	793.3
Sweet Corn	561.1	524.2	453.9	475.8	529.8	548.0	545.5
Dry Beans	587.0	548.3	475.9	498.8	553.0	571.4	569.1
Dry Onions	847.8	789.8	686.4	719.5	790.0	819.7	814.7
Early Potato	756.4	705.6	616.4	645.9	705.8	728.4	724.1
Mid-Season Potato	781.9	728.8	630.4	660.3	731.9	761.1	756.7
Late Potato	780.6	730.2	624.2	656.8	731.3	764.5	759.8
Green Bean	516.4	483.3	416.3	437.0	485.6	504.1	501.6
Sugar Beet	985.6	927.5	789.8	834.0	915.9	961.8	950.6
Spring Grain	713.7	664.2	588.8	615.3	664.2	681.2	676.2
Winter Wheat	553.7	513.3	466.7	488.0	513.0	523.1	515.8
WW Sweet Onion	338.5	313.9	281.6	294.5	310.9	319.1	316.3
Grass Hay	1013.2	950.4	830.3	877.7	950.7	988.7	973.3
Pasture	1196.5	1125.4	982.4	1043.9	1126.6	1176.2	1149.4
Hops	984.8	921.4	794.0	836.8	922.8	966.2	954.5
Spearmint	1145.9	1075.7	932.9	987.2	1070.5	1118.9	1101.0
Peppermint	941.8	886.2	762.5	808.6	883.8	927.1	910.3
Concord Grapes	826.2	778.5	670.2	711.5	775.3	813.4	797.5
Wine Grapes	377.4	355.6	299.3	316.2	652.3	372.4	368.3
Apples/Pears[b] w/cover	1182.7	1114.0	956.3	1014.1	1106.4	1160.8	1141.2
Apples/Pears[b] w/o cover	931.8	877.9	754.2	799.6	872.8	915.5	899.5
Stone Fruits[b] w/ cover	1099.0	1035.0	889.5	943.2	1028.5	1078.7	1060.2
Stone Fruits[b] w/o cover	839.2	789.9	680.1	721.2	787.0	824.6	810.0

(a) Penman alfalfa is the calculated value of evaporation based on an alfalfa reference over the whole year. It is indicative of clear water pond evaporation over the year.
(b) Many orchard crops are grown with (w/) grass cover crops between rows, which requires additional water. Orchards without (w/o) cover crops would be representative of drip-irrigated blocks.

2.7 Water Resources

Water resources within the Columbia Plateau region must be considered in a regional and international framework. Withdrawals from the Columbia River may have a large impact on downstream water users (domestic, municipal, industrial, and agricultural) and on recreation, navigation, and hydropower production. Human activities have negatively affected surface and subsurface water quality over broad areas. Reservoir releases for power and other uses are jointly coordinated by the U.S. Bureau of Reclamation (USBR) and the U.S. Army Corps of Engineers to manage often competing demands. Withdrawals from deep confined aquifers affect piezometric levels in wells over large areas. In addition, specific recharge areas for the deep aquifers are largely unknown, but may be hundreds of kilometers from the withdrawal locations.

2.7.1 Surface Water

The Columbia River is the dominant surface water source at the Hanford Site. It rises in Canada along the western side of the Selkirk Mountains in British Columbia and enters Washington State north of Spokane before heading west and then south to the Hanford Site, where it makes a bend to the east before going south and to the west. It is the second largest river in the contiguous United States in terms of total flow. The Columbia River drains a total area of 680,000 km^2 (262,480 mi^2) and is about 2000 km (1243 mi) long. It flows into the Pacific Ocean and forms much of the boundary between Oregon and Washington. Major tributaries include the Snake and Yakima rivers, which join the Columbia River in the Tri-Cities area.

Average discharge at the mouth of the Columbia River is about 7250 m^3/s (256,000 ft^3/s). Irrigation diversions throughout the entire Columbia drainage area currently account for less than 5% of the total annual flow at the mouth of the river. Average daily flows of the Columbia River in the Hanford Reach range from 1000 to 7000 m^3/s (36,000 to 250,000 ft^3/s), which are largely controlled by upstream releases from Grand Coulee Dam.

Some communities and the Hanford Site use the Columbia River for municipal and industrial water supplies. However, the primary uses of the Columbia River are hydropower production and irrigation. In addition, recreational uses of the Columbia River include sport fishing, hunting, boating, sailboarding, swimming, water skiing, and diving. Considerations for threatened and endangered species of fish currently impact the total management of the Columbia River resource. The substantial amount of electrical power produced in the region from hydro, nuclear, and other sources also relies on water from the river system and has a major regional economic impact.

The Yakima River borders a short length of the southern boundary of the Hanford Site. Average annual flow is about 104 m^3/s (3712 ft^3/s). Approximately one-third of the Hanford Site is drained by the Yakima River system. Surface runoff from the Hanford Site is estimated to be about 3% of the total annual precipitation to the area.

2.7.2 Groundwater

Unconfined and confined aquifers underlie the Hanford Site, both of which would be available for future agricultural development of the area. Many small municipalities and industrial users that are not adjacent to the rivers use deep, confined aquifers as a water supply. The Tri-Cities communities use a mix of Columbia River and supplemental groundwater sources (confined and unconfined aquifers), whereas almost all rural domestic (homesteads and livestock) water comes from unconfined aquifers (<100 m deep). Groundwater from both aquifers systems is used for irrigation.

The Ringold and Hanford formations compose the unconfined system, which is directly connected to and discharges into the Columbia River. Unconfined groundwater flow direction at the Hanford Site is predominately from west to east. Specific yields for the Ringold formation typically range from 0.05 to 0.2 and from 0.1 to 0.3 for the Hanford formation. Effective porosity ranges from 0.01 to 0.37, with an average value estimated to be about 0.25. Groundwater quality is generally quite good with relatively low salt levels, although domestic wells usually require a water softener because of calcium carbonates precipitates. In addition, there are localized plumes of contaminants from past Hanford operations (i.e., tritium, iodine-129, uranium, technetium-99, strontium-90, trichloroethylene, chloroform, and carbon tetrachloride) in the unconfined aquifer system.

The saturated thickness of the unconfined aquifer system varies from close to zero near the basalt ridges and Rattlesnake Mountain to the west to more than 60 m near the Columbia River. Depth to groundwater ranges from less than 0.3 m near the river to more than 100 m elsewhere on the Hanford Site. Recharge to unconfined aquifers is from runoff from the elevated areas along the western side of the site (i.e., Rattlesnake Mountain), spring discharges from the extensive confined aquifer system, artificial recharge from processing waste water disposal, and local precipitation. There is a direct hydraulic connection to the Yakima and Columbia rivers.

Within the Pasco Basin, the Columbia River Basalt Group consists of the Saddle Mountain, Wanapum, and Grande Ronde basalts. These subsurface basalt groups contain numerous confined aquifers associated with the more permeable interflow and interbed zones generally located between the dense, columnar confining units. Yields range from quite small to quite large. The locations of recharge areas for these aquifers and hydraulic connections between the various confined aquifers are not well understood. Hydraulic connections between the confined and unconfined aquifers also exist due to substantial artesian pressures (from 300 to 400 m of head in some cases) in the confined aquifers. Some of these aquifers are extensively used for large-scale irrigation in areas not served by the various Columbia River Basin irrigation projects. Piezometric pressures are declining in some confined aquifers in some areas as a direct result of agricultural and municipal pumping. Water quality is good with low levels of total dissolved solids. However, most of the salts are sodium bicarbonates, which require that the water always be treated with acids to lower pH before any agricultural use. These deep aquifers would be available for future agricultural uses on the Hanford Site. However, because of recently observed declines in hydraulic head, their long-term sustainability for large-scale development is doubtful and needs more study.

An analysis of well data was derived from records on file with the Washington Department of Ecology (WDOE) in Spokane. The information contained in these records was very sparse in most instances. Domestic well data are likely incomplete, whereas the other categories are close to actual. Table 2.3 summarizes the characteristics of the domestic, industrial, irrigation, and municipal wells in the study area that were registered with the WDOE.

Table 2.3. Summary of Well Characteristics for all Wells by Major Use Category Within the Study Area Based on WDOE Well Permit Records (values in parenthesis are one standard deviation)

Use	Total Wells	Number of Wells with Screens or Perforations	Average Screened Length, m	Average Depth, m	Average Discharge, l/s
Domestic	116	19	6.6 (4.81)	86.1 (76.49)	4.54 (10.92)
Industrial	38	18	6.8 (9.39)	84.4 (72.75)	22.3 (31.75)
Irrigation	883	443	9.8 (7.04)	116.7 (126.14)	81.6 (78.85)
Municipal	57	18	20.8 (29.05)	182.5 (110.26)	36.4 (52.30)

The WDOE records for 1226 wells in the study area surrounding the Hanford Site were analyzed and characterized. There were 883 wells classified as irrigation, 116 as domestic, 38 as industrial, and 57 as municipal. Another 132 wells were registered as "fish" (11), "other" (24) or "test" (97). It is safe to assume that the domestic category may not be accurate because it is highly probable that numerous domestic wells in the area were not registered with WDOE and some domestic users are also using water classified as "irrigation."

Figure 2.4 is a frequency distribution of well depths in the study area based on the WDOE records. There is tremendous variability in these records, and statistical measures describing the distributions have limited use. The majority of wells (799), and the largest numbers in the bimodal distribution, are primarily located in the unconfined aquifers. However, a number of wells less than 60 m deep are high-volume wells located in unconsolidated gravel deposits near the Columbia River (i.e., 56% of all irrigation wells were less than 60 m deep). Figure 2.5 shows well depth distribution by use. Most of the wells deeper than 100 m (426) are withdrawing water from the confined aquifers in the basalts and are used for large irrigation (35% of irrigation wells) or municipal purposes (72% of municipal wells).

Many of the wells were only partially cased, leaving portions of the bore holes open, particularly in the basalt formations. Less than 41% (498) of all four major categories that were examined had screens, perforations or both.

Screen length is an indication of the thickness of the water bearing strata. There are 573 wells out of the 1226 and 498 from the four major categories that have screens and/or perforations. Figures 2.6 and 2.7 show the distribution of the length of screens (and/or perforations) for all wells and all categories by

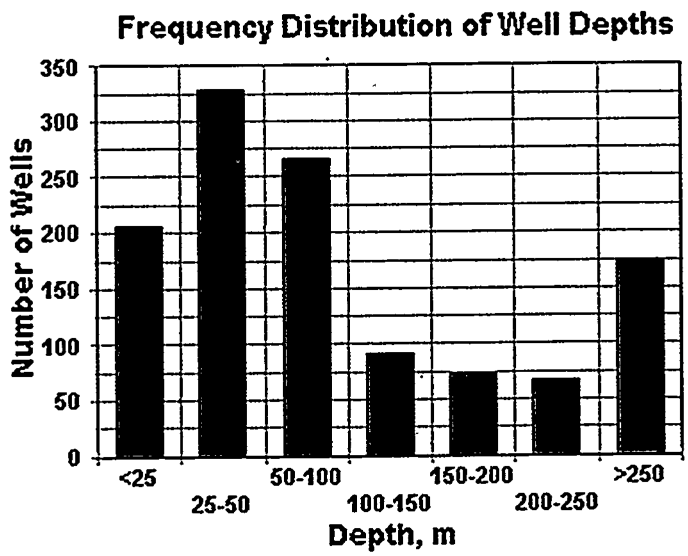

Figure 2.4. Frequency Distribution of Depths for 1225 Nearby Wells in the Areas North and East of the Hanford Site Based on WDOE Filed Well Records

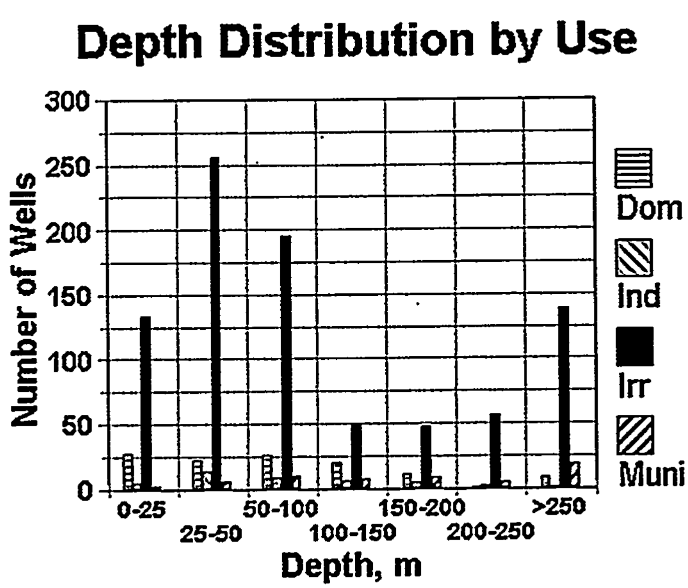

Figure 2.5. Frequency Distribution of the Depth of Wells by Use in the Study Area Based on WDOE Filed Well Records

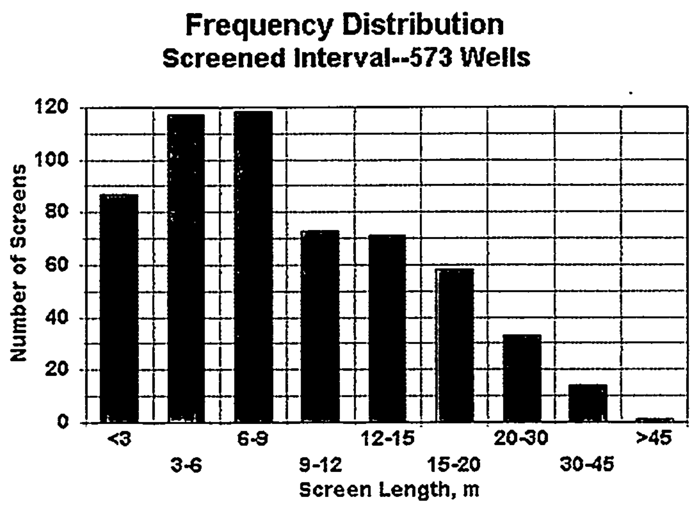

Figure 2.6. Frequency Distribution of the Length of Screens or Perforations of 573 Wells Near the Hanford Site

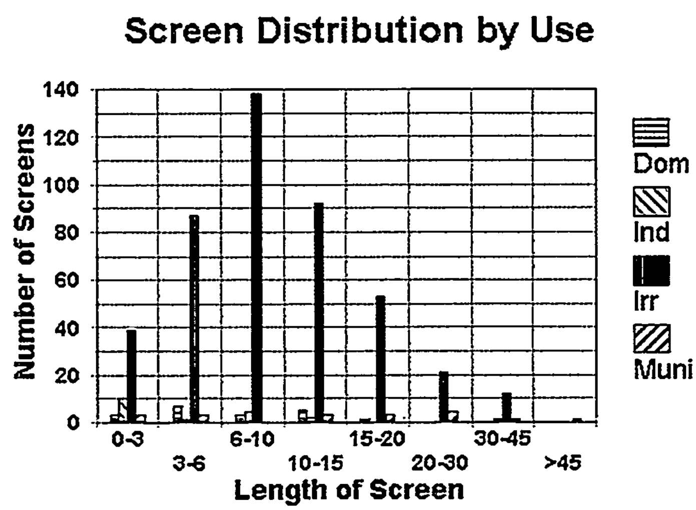

Figure 2.7. Distribution of the Length in Meters of Well Screens or Perforations by Major Use Category (498 wells since test and other miscellaneous types of wells are not included)

use from the permits that were examined. Fifty percent of the irrigation, 16.4% of the domestic, 43.6% of the industrial, and 32% of municipal wells are screened and/or perforated. The average length of screened interval for all wells of all types is 9.5 m, with 41% between 3 and 9 m. The majority of the wells in the unconfined aquifers have screens and/or perforated casings.

Three-fourths of the domestic and almost two-thirds of the irrigation wells are less than 100 m deep and most likely in the unconfined aquifers. Most of the water extracted by sustained, higher yielding wells in the unconfined aquifers is likely from irrigation return flows or direct hydraulic connections to the rivers. Natural recharge to the water tables is small. For wells less than 100 m (300 ft) deep, the average discharge for domestic wells is about 4.5 l/s (72 gpm), for irrigation wells 75 l/s (1200 gpm), for industrial users 23 l/s (360 gpm), and for municipal wells 26.4 l/s (420 gpm). Table 2.4 characterizes wells less than 100 m in the study area.

Table 2.4. Summary of Well Characteristics for Wells Less Than 100 m in Depth Within the Study Area Based on WDOE Well Permit Records. (Values in Parenthesis are one standard deviation)

Use	Number of Wells <100 m	Number of Wells <100 m with Screens or Perforations	Average Screened Length, m	Average Depth, m	Average Discharge, l/s
Domestic	76	13	6.17 (4.16)	40.3 (22.37)	5.24 (12.98)
Industrial	25	16	4.6 (3.77)	40.2 (19.52)	21.1 (33.29)
Irrigation	583	412	9.7 (7.01)	41.2 (19.82)	75.3 (83.74)
Municipal	18	6	7.2 (6.16)	58.0 (23.41)	24.7 (50.76)

3.0 Agricultural Development in the Region

Central Washington is one of the most productive and diverse agricultural areas in the world. Some of the highest yields ever measured for many crops have been reported there. Over 80 different crops are typically grown in the region every year including many high-value specialty crops. Because of the low annual rainfall in the region (from 150 to 200 mm/yr), development of high-value agriculture has depended on irrigation to supplement natural precipitation. In addition, the area has abundant, high-quality water from the Columbia River and low-salinity soils.

Soil erosion by wind and water is a significant problem, but can be minimized with appropriate agricultural practices. Waterlogging of soils tends to be localized in small areas because of subsurface bedrock topography, but is easily controlled by installing subsurface drainage systems.

A well developed infrastructure is in place to support large-scale agriculture in the region, including transportation (excellent road, rail, and river transport systems), strong electrical power network, service industries, equipment retailers, and research centers (WSU and the U.S. Department of Agriculture (USDA)-Agricultural Research Service). Large investments have been made in food processing and storage facilities, especially in the Tri-Cities area. This infrastructure would be available to support any future agricultural development of the Hanford Site.

Irrigated agriculture and its related industries (agricultural services, food processing, transportation, and retailing) is, and will continue to be, a fundamental part of the state's economy. Annual production from the state's irrigated lands exceeds $3.5 billion at the farm gate and is a major source of exports. A large infrastructure has been developed for processing, transporting, and retailing agricultural products with huge large economic effect on the regional economy. Secondary processing of agricultural products is estimated to add an additional $20-25 billion a year to the state's economy.

The region's agricultural industry affects almost all economic sectors, resulting in purchase of billions of dollars in goods and services every year. It provides a stable base for growth in other sectors as it quietly, steadily, and reliably produces a huge proportion of the state's income.

Yakima, Grant, Franklin, Benton, and Walla Walla Counties, which surround the Hanford Site, are the top five counties in Washington, respectively, in terms of the farm gate value of their agricultural production. Washington State currently ranks 15th nationally in the value of its total agricultural output (farm gate: livestock and crops) with a substantial portion of that output from irrigated agriculture in this region. Washington is ranked 8th nationally in total crop value, 3rd in vegetables, and 3rd in the production of fruit and nuts. The region's crop production is high, and it is reasonable to assume that irrigated agricultural production would be similar for the Hanford Site. The Appendix summarizes the current agricultural production in Grant, Adams, and Franklin Counties.

3.1 Irrigation Development

The main irrigated areas near the Hanford Site are the Yakima River Project and the Columbia Basin Project. Both of these projects were built by the U.S. Department of the Interior, Bureau of Reclamation. Several large-scale private irrigation developments also exist to the south and east of the Hanford Site on sandy soils, which are almost exclusively irrigated by center pivot machines.

Starting about 25 years ago, a relatively small irrigated area was developed adjacent to the northern boundary of the Hanford Site (along Cold Creek) for the production of wine grapes and fruit trees. Recent developments include center pivoted irrigated alfalfa and potatoes (however, these will likely be converted to drip irrigated wine grapes in the near future). These developments are significant to this study since they successfully demonstrate the types of crops that could be grown in many parts of the Hanford Site with similar slopes, aspects, and soil types.

3.1.1 Yakima River Project

The Yakima River Project is the oldest irrigation development in the region and contains about 182,000 actively irrigated hectares (450,000 acres). Six main irrigation districts operate in the project with about 20 small, private districts that typically irrigate less than 1000 hectares (2,500 acres). The Kittitas Irrigation District serves the Ellensburg area in the upper Yakima Basin. The Tieton, Roza, Sunnyside, and Wapato (Yakama Indian Reservation) irrigation districts serve lands in the lower Columbia Basin from near Yakima to the Tri-Cities. The Kennewick Irrigation District serves lands in the Badger Canyon and west Kennewick areas. Land ownership in the Columbia Basin is about 40% federal, 30% Native American, and 30% private.

The earliest irrigation recorded in the Yakima River drainage is in 1852 in the Ahtanum Creek near a Catholic Mission and in 1853 when construction of the Indian Ditch near Tampico began. Cattlemen and sheep herders were attracted by the abundance of bunch grass and wild game. Miners started arriving in 1854, leading to conflicts with Native Americans and the construction of Fort Simcoe. Settlers arriving as early as 1861 developed additional irrigation along the Naches River. Additional irrigation diversions near Prosser and Kiona were in existence around 1878. In 1886, completion of the Northern Pacific Transcontinental Railroad spurred new agricultural expansion in the region. The railroad company and several private land development companies made large investments in irrigation to aggressively attract settlers. By 1900, after construction of the early Sunnyside and Congdon Canal systems, the Yakima Valley was the largest irrigated area in the state with about 48,600 hectares (120,000 acres) irrigated.

In 1905, Congress authorized the 200,000 hectares (500,000 acres) Yakima Federal Reclamation Project to be built by the USBR). Construction funds for the Tieton and Sunnyside divisions were authorized in 1906. Over the next 20 years, construction of the Kittitas, Roza, and Kennewick divisions were authorized, and six reservoirs were constructed. Today, the USBR manages the surface water supply in the Yakima Basin through control of reservoir releases.

Starting in the late 1890s and completed in the 1950s, the Wapato Project was constructed and managed by the Bureau of Indian Affairs (BIA) on Yakama Indian Reservation lands south of the Yakima

River. The BIA contracted with the USBR to supply water for the Wapato Project. Most of the natural flows of Toppenish, Simcoe, and Satus Creeks are also captured and used within the district.

Many of the earliest irrigation developments were consolidated into the various federal Yakima Basin projects. A considerable amount of water is reused and shared within and between irrigation districts by capturing return flows and water markets.

An undefined amount of water is pumped from both shallow and deep wells inside and outside the irrigation district lands (estimated at an additional 20,000 hectares [50,000 acres]). The deep wells are in the confined aquifers in the basalt and relatively high yielding. Shallow wells in the unconfined aquifers are mostly for domestic use since they generally have low yields (<6 l/s), except for some localized gravel deposits in the Wapato Irrigation District that have high yielding wells.

Orchards were planted early in the agricultural development of the lower Yakima Valley. Railroads provided rapid transportation of produce to urban markets, and the fruit industry grew and continues to flourish. Hops were introduced into the area in the early 1900s. Wine grapes were planted before the turn of the century, and although the industry died due to prohibition, it has made a major resurgence starting in the late 1970s. Concord grapes have been grown for juice since the 1940s. In general, there is a high percentage of permanent crops.

Because of the limitations of available agricultural production technology before World War II and the high labor requirements of orchard, vine, and hop, the general tendency in the area is to maintain small individual fields (<15 hectares [<40 acres]). The rugged and/or steep topography combined with early irrigation methods that eroded the surface also mandated small fields in many areas, particularly on higher lands in the Roza and Sunnyside Districts. Crops grown in the Kittitas area are mostly small grains, Timothy hay, alfalfa, pasture and field corn, and a small number of orchards. Field sizes are also generally small for many of the same reasons.

Originally, all of the water was applied by furrow and ridge methods (gravity-flow surface irrigation), but presently less than 20% of the lands use these methods. Solid set sprinklers and microirrigation (drip and micro sprinklers) methods have largely replaced older methods. There are few center pivots. The initial shift to adopt pressurized irrigation methods was driven by the benefits of frost protection and erosion control (cover crops) for the rapidly increasing permanent crop industries (orchards and vineyards) in the area. However, current restrictions on return flows to the river imposed by the Endangered Species Act have resulted in many conversions of the remaining surface irrigated lands to pressurized methods. It is expected that within a few years, surface irrigation will be used in only a few small areas of the basin.

Currently, Yakima County is ranked tenth in the list of leading agricultural counties in the United States. It ranks first in the nation in the production of hops, apples, and mint. More than 80 crops are grown including wine and juice grapes, mint, asparagus, sweet corn for processing, cut flowers, and alfalfa hay. The county is a major center for beef cattle feeding in the state, and numerous large dairies have located in the area.

3.1.2 Columbia Basin Project

The Columbia Basin Project (CBP) has three irrigation districts: the Quincy District, the East District, and the South District, which are located to the north and east of the Hanford Site. The CBP service area contains portions of Grant, Adams, Lincoln, Franklin, and Walla Walla counties. The South District lands are adjacent to the Hanford Site (across the Columbia River to the east and north). Construction of the CBP began in 1933, and the first water was delivered in 1952. The last block to be developed was Block 26 in the Mattawa area, just north of the Hanford Site.

Congress initially authorized the CBP to irrigate about 405,000 hectares (1,000,000 acres); however, because of a subsequent moratorium on future development of the project, only about 60% of the original area is currently irrigated with project water. The East High canals were never constructed even though many of the head works and siphons needed to supply the water to the area were built. An estimated 30% of the original East High area is currently irrigated using water from deep wells in the confined aquifers that were privately developed; however, it is doubtful that this is sustainable due to pumping costs and the cumulative effects of using high-sodium groundwaters on soils.

Current acreage figures also include about 16,320 hectares (40,300 acres) being irrigated through "artificially stored groundwater" or subsurface return flows from other project lands in the Black Sands area near George, Washington that were not part of the original project Irrigation has expanded (about 32,000 hectares [80,000 acres]) to "marginal" lands in other parts of the CBP because of advancements in irrigation technologies (i.e., center pivots and drip) that were not available when the project was designed. Annual production from CBP lands contributes more than $800 million in direct and secondary income that benefits several counties.

Most CBP water comes from Grand Coulee Dam, located on the main stem of the Columbia River about 90 miles west of Spokane. Natural inflows from Crab Creek, Rocky Ford Creek, and other natural tributaries provide small contributions (generally <1% of total project needs) to the project's water supply. Irrigation canals and other project works extend southward from Grand Coulee Dam about 125 miles to the vicinity of Pacso, Washington near the confluence of the Columbia River with the Snake and Yakima rivers. The Columbia River forms the western boundary of the project.

The CBP diverts about 3% (standard deviation about 5%) of the annual inflows to Lake Roosevelt, 0.3-0.33 M ha-m (2.5-2.7 MAF), to irrigate more than 251,840 hectares (622,000 acres) of land. With return flows back to the Columbia, the net water withdrawal from the Columbia River is about 1% of the total annual runoff of the entire river basin, 24.4 M ha-m (198 MAF). The average on-farm delivery is about 1.13 ha-m/ha (3.7 acre-ft/acre). Average annual crop irrigation requirements are estimated at 0.83 ha-m/ha (2.71 af/a) (Montgomery Water Group 1997).

Water delivery to farms (per unit area) has decreased since the project began because of changes in irrigation practices and some changes in cropping patterns. Farmers have converted from less efficient gravity irrigation systems to more efficient pressurized methods such as center pivots and drip or micro-irrigation methods. Since 1969, the percentage of farmers using pressurized irrigation systems has increased from 40% to 70% across the entire project. About 90% of the South District uses pressurized systems, as does the Wahluke Slope (Mattawa) irrigated areas. All three irrigation districts actively encourage and provide assistance to their growers to convert to pressurized systems, greatly accelerating this trend. Also, the rapid conversion in some areas to orchard and vine crops and specialty seed crops (i.e., carrot seed), which use much less water than do historical crops, has helped to reduce water requirements. The CBP is the most rapidly growing orchard and vine crop area in the Pacific Northwest.

In 1993, the USBR issued a moratorium on all further water development in the CBP in response to requests from the Northwest Power Planning Council and the National Marine Fisheries Service. At the same time, the water resources agencies in Washington, Idaho, and Oregon simultaneously announced that they would no longer issue permits for new diversions in the basin's salmon streams. Thus, it is highly likely the CBP irrigated acreage will remain at present levels in the future.

3.1.3 Historical Irrigation in the Hanford Site

In 1818, Fort Nez Perce was founded near present day Wallula to protect fur trappers and traders. It was later renamed Fort Walla Walla. The permanent non-Indian settlers in the area were largely cattle ranchers. The area's mild winters, sand grass, and white sage fattened cattle that were driven the Vancouver, Canada and other regional markets. However, extreme cold and heavy snowfalls during the winters of 1880-81 and again in 1886-87 decimated the cattle industry. Settlers then began building small dams and canal systems using gravity flow irrigation methods along the lower Yakima and the Columbia rivers. Most of the early irrigated crop produced on the Hanford Site was hay for feeding livestock. From 1880 until the early 1890s, numerous homestead claims were filed in the Wahluke Slope/Hanford Reach area.

During the early 1900s until 1943, the area continued to grow. The towns of White Bluffs, Hanford, and Richland flourished. Irrigated areas produced apples, cherries, pears, alfalfa, potatoes, and many other vegetables. Beef cattle, horses, chickens, pigs, dairy cattle, and large flocks of sheep were raised and grazed in the area. The average 160-mm (6.3-in.) annual precipitation made production of rainfed or dryland crops such as wheat and barley impractical. In 1954, the USDA rated the soils in the Hanford Site as marginally suited for cultivation, primarily because of the type of irrigation (gravity flow) available at the time (USDA 1954). However, with the advent of pressurized sprinkler and micro-irrigation technologies, these early classifications are no longer valid as has been convincingly demonstrated in many nearby areas.

In March 1943, all the private lands within the current Hanford Site boundaries were acquired by right of eminent domain by the U.S. Government for the Manhattan Project as part of the war effort. The land has passed from the U.S. Department of Defense to DOE, which now operates and maintains the Hanford Site. Since 1943, there has been no agriculture within the site.

4.0 Agricultural Technologies

It is an exciting time to be involved in agriculture. The state of the art of agricultural technology is advancing extremely rapidly. Crop production methods and management 50 years from now undoubtedly will be much different than today. Agrichemical restrictions, environmental concerns, and the need to be competitive in world markets are fueling tremendous strides along many fronts improvements. This section explores some of the more probable future developments in agriculture and examines current technologies and the economic impacts of irrigated agriculture in the region.

Future farm management and cultural practices will be much different from today. Bioengineered plants will be more common because they will be more resistant to insects and disease, more salt tolerant, and will use nutrients and water more efficiently (less water will be needed). The production of pharmaceuticals will be more common in agriculture in addition to food and fiber. Biologically based pest control combined with genetically engineered crops resistant to many plant diseases will continue to reduce agrichemical use.

The development of site-specific, integrated real-time precision irrigation, fertigation and pesticide systems is currently underway. Global positioning systems (GPS), detailed field-yield monitoring, GIS, computer models, extensive field sampling programs, and real-time monitoring of climate and field parameters make it possible to optimize crop management for spatial and seasonal variability. Inputs can be optimally matched to yields, greatly reducing costs and improving environmental stewardship. Advances in remote sensing, crop protection, precision planting, precision tillage, precision irrigation, and harvest mapping are changing agriculture. Collectively, these are referred to as precision agriculture.

4.1 Precision Agriculture

Precision agriculture means carefully tailoring soil and crop management to fit the different conditions found in each field using a wide variety of technologies. Precision agriculture is sometimes called precision farming, prescription farming, site-specific farming, site-specific crop management or variable rate technology. It involves aspects of remote sensing, crop protection, precision planting, precision tillage, precision fertilizer placement, precision irrigation, on-the-go yield monitoring and other emerging applications. Some of the emerging technologies undoubtedly will be part of future crop production systems in the Pacific Northwest (Evans 1997a,b). Emerging technologies have the potential for reducing inputs, and improving use of existing resources, improving environmental stewardship, and improving farm profitability.

Some believe that the potential consequences of precision agriculture technologies will have as great an impact on future agricultural production as the "green revolution" is having currently. However, at present the technology is ahead of the science to use it correctly. Research is currently underway by universities and the USDA to give farmers confidence that the use of these technologies is practical and potentially valuable for improving production of irrigated crops in the near future.

The U.S. Congress has published the following definition of precision agriculture:

"Gathering on-farm information pertaining to the variation and interaction of site-specific spatial and temporal factors affecting crop production. Use of that information to prescribe and deliver site-specific applications of agricultural management practices and inputs to maximize productive efficiency while minimizing negative environmental impacts." (House Bill 725, 105th Congress, 1st Session, February 12, 1997)

Congress extended this concept by defining precision agriculture technologies to be:

"Instrumentation and techniques ranging from sophisticated sensors and software systems to manual sampling and data collection tools that measure, record and manage spatial and temporal data. Technologies for data processing that produce valued information for farm management decisions. Machines that deliver information-based management practices and inputs to accomplish the objectives of precision agriculture."

Thus, precision agriculture is basically about information: its collection, management, and interpretation. It has been made possible by advances in computer and communications technologies that allow growers to use equipment and software to manage inputs in ways that account for the inherent yield variability across any field. Precision agriculture is a systematic way to look at the total farming operation.

The necessary "components" to implement precision agriculture on irrigated lands have recently become readily and economically available. These include: 1) GPS, 2) GIS, 3) improved techniques for real-time remote sensing of soil and crop status, and 4) improved computers, communications, "smart" sensors, and monitoring systems to provide adequate feedback and control capabilities. These improved techniques for remote sensing of soil and crop status, [already discussed above], [already discussed above], advanced crop growth and disease models, [already discussed above], and real-time data collection systems that provide adequate feedback and control capabilities make it possible to develop integrated, economically viable, site-specific crop management systems. These data must be used with software to statistically evaluate, enhance, and spatially combine with other GIS data layers to look at inter-relationships and causes of yield variability.

Yield monitors, grid sampling, and remotely sensed data are valuable tools that provide critical information on field variability and evaluate the results of a site-specific management program. The amounts of water (and nitrogen) applied by center pivot and drip irrigation systems can be carefully managed to match the spatial variability in water holding capacity and related nutrient availability. Yields and crop quality are affected by many factors. Variations in quality and quantity of yields are increased by weeds, pests, and pathogen effects on crop growth as well as microclimate changes across a field, which can cause further variability in water and nutrient usage. In addition, the method used to correct one problem may have unwanted side effects that create new, and possibly more serious, problems that must then be corrected.

The large potential of precision agriculture is recognized by fertilizer companies and major farm equipment companies such as Ag Chem, John Deere, Case-IH, Heston and others, who are making significant efforts to develop various applications. Companies like CENEX-Land 'O Lakes, Simplot Soilbuilders, and others are making large investments in equipment and employee training to provide related services. Self-propelled irrigation system manufacturers are also very interested and conducting research in precision agriculture. Software for site-specific evaluation is becoming more available at low prices.

Research is underway around the world to fit the various components of precision agriculture together. These are 1) optimizing yields and quality from each area within a field, 2) reducing product variability, 3) protecting the environment, 4) reducing inputs, and 5) maximizing returns on investments. Ideally, processing and marketing parameters also should be included to form a holistic approach to agriculture.

Because growers must irrigate in the arid west and can control soil water, they can maximize the benefits of many precision agriculture technologies. The arid climate of the Hanford Site enhances management ability since uncontrolled natural precipitation is a minor factor, and its influence is easily included by adjusting irrigation management strategies/programs. This can greatly reduce drainage/deep percolation losses.

Advances in farm equipment and management capabilities that are part of precision agriculture or precision farming will undoubtedly influence all of the world's agriculture in the next century. The alternative management practices of precision agriculture technologies will be fundamental to profitable and sustainable farming in the future. Environmental issues, reduced water supplies, and reduced availability of chemicals/pesticides must be addressed, and components of precision agriculture will be a part of the solution. Precision agriculture can make U.S. producers more competitive, and agrichemical use will be reduced to minimum levels.

4.2 Irrigation Technologies

Irrigation technology has advanced significantly since World War II. Center pivots and microirrigation techniques were developed in the 1950s and 1970s, respectively. These technologies are continuing to evolve. Thus, future decisions must be based on the current and expected advances in irrigation technologies for application of water and agrichemicals as well as management. The best area on which to base future agricultural land use for the Hanford Site is the CBP lands that are adjacent to the site to the north and east.

To select the type of irrigation system to install, a number of different factors must be considered. These include the crop and crop water requirements; water supply; soil characteristics; topography, size, and shape of the field; climate of the area; and economic factors such as labor requirements, available capital, and resource costs. Many of these factors are interdependent, and while one factor may or may not indicate a definite need for a particular irrigation method (or even the need for irrigation), the relationships between these factors must be considered.

Many crop factors influence the irrigation system choice. For crop consumptive use, both the total seasonal water needs and the pattern of water needs during the season (relative to growth stages) compared to rainfall amounts and patterns determine the net irrigation requirements. Net irrigation requirements (over and above rainfall) range from only 125 to 300 mm (5 to 12 in.) of moisture for short-season vegetable crops and wine grapes to 630-900 mm (25 to 35 in.) for orchard and forage crops. The actual amount depends strongly on crop and location. Average daily peak period water needs for most Eastern Washington crops and locations is from 5 to 7 mm (0.20 to 0.28 in.) per day. This translates to a required continuous supply of from 1 to 1.2 L/s/ha (4 to 6 U.S. gallons per minute per acre) to be supplied by irrigation. Wetting of the crop foliage or fruit may cause disease or pest control problems, and depending on the quality of the irrigation water, crop wetting may not be recommended to avoid quality or toxicity problems. Lack of aeration in the root zone over time may reduce plant performance. Cultivation requirements or other cultural practices may preclude the use of certain methods. The expected economic return of the crop in both quantity and quality must be analyzed to determine how much can be invested in irrigation.

Water supply factors include the quantity and quality of the source. The kinds and amounts of any salts dissolved in the water must be known. Central Washington has high- quality, abundant surface water supplies with low soil salinity. The availability of the water (timing and frequency) affect the design and management of an irrigation system, and boosts the required supply rate if the supply is not continuous. The size of the available stream may limit the choice of systems to only the most efficient. If water is not available during critical dry periods or critical growth stages, irrigation is moot.

Soil characteristics that must be assessed include the infiltration rate, water holding capacity, depth, drainage conditions, reaction to water and salts, and soil erodibility. The variability of these properties throughout a field must also be known. The rate at which soil accepts water (the infiltration rate) will often eliminate some methods of irrigation. The soil water holding capacity and the depth of the soil in conjunction with the crop rooting depth, the crop water requirements, and climatic conditions may actually indicate irrigation is not needed, i.e., enough water is held in the soil and available to the crop for the entire growing season or to carry the crop during dry intervals. Typically, this will only be the case for deeper rooted crops grown on finer textured soils, or where dry spells during the summer are of short duration. Soil drainage conditions are extremely important in western Washington. Soils that do not have adequate natural drainage may rapidly become waterlogged under irrigation. Applied irrigation water may be lost in runoff and valuable topsoil may be eroded.

Field size, shape, and topography require differing degrees of flexibility in the irrigation system. The topography of the field may require extensive land leveling to use certain methods. Certain irrigation methods are not recommended for steep slopes, and others require special design requirements. All these factors increase the cost of the system.

Climate is the driving factor in determining crop water requirements and the need for irrigation to provide the portion of the requirement not met by precipitation. Seasonal and annual variations in climate will often decide the need for irrigation to produce high yields of high-quality crops in environments that otherwise do not need irrigation. This is also the case when irrigation is used for environmental modification to protect the crop (e.g., frost protection).

Irrigation as a cultural practice adds costs to production. Initial capital costs vary widely from method to method. The method chosen also affects total costs for irrigation water, energy, labor, and land preparation. In considering the economics of irrigation systems, trade-offs exist between costs of capital, labor, water, energy, and land. The system yielding the highest return is a compromise between these resource costs. Table 4.1 shows the range of typical capital and annual costs of the various irrigation methods. Capital costs include materials and construction of the irrigation system but does not include the cost of land, land preparation, and water source development costs. Annual costs include labor, amortization of the irrigation system, and energy costs (to pressurize the system, if needed) but does not include the cost of water, taxes, interest charges or amortization of the water delivery system (e.g., pump and well).

Furrow irrigation is a limited option at the Hanford Site because of high sand soil texture classifications. The small amount of silt loams may be suitable but are subject to severe erosion. Soil erosion is being addressed successfully by growers using formulations of polyacrylamide (PAM) in small quantities essentially to halt furrow irrigation-induced erosion on thousands of acres in the Yakima Valley and the CBP (details are on the Internet at http://kimberly.ars.usda.gov/pampage.ssi).

Table 4.1. Comparative Approximate Range of Initial and Annual Costs per Hectare (Including Labor) of Various Irrigation Methods, Not Including Land Purchase, Taxes or Water Development Costs

Method		Capital Costs		Annual Costs	
		Low, $	High, $	Low, $	High, $
Surface:					
	Furrow (rill)	500	1000	250	450
	Furrow w/Land Leveling	600	1500	250	450
	Furrow w/Automation	750	1600	300	500
	Furrow w/Tailwater Reuse	750	1500	300	600
Sprinkle:					
	Aluminum hand-move	875	2000	375	600
	Wheel-move	875	1850	225	500
	Center pivot	1000	2000	375	1100
	Precision System	1250	2500	450	1200
	LEPA	1250	2500	450	1100
	Traveling gun	1000	2000	250	1250
	Solid set	1850	3700	250	1000
Microirrigation:					
	Drip/trickle	1850	3700	500	1000
	Micro-sprayers	1900	4500	500	1000

The most appropriate irrigation methods for most of the Hanford Site, based on current technology and expected advances, will probably be self-propelled center pivots, linear move irrigation systems, and microirrigation. These methods are discussed in more detail below.

The amount of water that can be saved depends on the ability of a particular type of irrigation system to improve management. However, the major factor is grower knowledge and the existence of incentives to adopt the improved management practices. A critical link in improved management is the implementation of scientific irrigation scheduling (SIS) techniques that will be required for any irrigation scheme.

4.2.1 Irrigation Scheduling

Irrigation scheduling is generally defined as deciding when to irrigate and how much water to apply. All irrigators schedule their irrigations differently. Some follow a calendar, while others irrigate because their neighbor is watering. Whatever criteria are used, relatively few irrigators currently use an approach based on sound scientific principles, or, SIS.

In general, a fairly large number of studies throughout the western United States shows that scientific irrigation scheduling can, in most cases, reduce the gross amount of water normally pumped from 15% to 44%. Water savings of about 20% seems to be a generally achievable level over "non-scientific" methods.

The concept of scientific irrigation scheduling (SIS) involves soil water holding capacity, volume balance, application efficiency, crop stress related to productivity and economic benefits, when and how much to irrigate, and how to apply the target amount of water. All SIS methods are based on two fundamental approaches, 1) monitoring soil and/or plant water status, and 2) predicting irrigation schedules from a computed soil water budget that estimates water depletion in the root zone. The first approach provides a direct reading of soil/plant status in the field and of water use since the last reading, but limits the potential for forecasting or planning. The second approach provides a planning element but alone does not have a "ground truthing" component as a baseline check to ensure accuracy. Thus, most SIS methods use a combination of the two approaches with wide variation in frequency and rigor of ground truthing activities and the development of new schedules.

Scientific irrigation scheduling is a concept that dates from the early 1950s. However, despite decades of promotion by public agencies and private consultants, its success and dissemination has been limited. As a result of recent droughts, groundwater contamination issues, and endangered species programs, growers are much more willing to look at SIS seriously as a viable part of their operations. Farmers in the Pacific Northwest are sensitive to the increased public demands that irrigated agriculture conserve more water and reduce agrichemical usage by using improved irrigation methods and better management. The shift away from low-energy surface irrigation methods to moderate to high-energy pressurized sprinkler and microirrigation techniques is accelerating, causing additional demand for electric energy and creating an even greater need to conserve electric power in the region. These factors, in addition to using irrigation systems for multiple purposes (e.g., frost protection and crop cooling) and adopting new irrigation methods is creating interest in and acceptance of SIS. SIS Irrigators are now more open to educational opportunities that will help them stay competitive. Recent successful SIS projects in Washington have also contributed to growing local approbation. The major incentives for adopting SIS currently are related to the cost of SIS services/technology and the cost of water, which includes the expense of pumping. Environmental regulations seem certain to provide additional incentives in many areas throughout the Pacific Northwest.

Educational programs are the only way to address problems related to an irrigator's insufficient knowledge of 1) irrigated soil properties; 2) irrigation system application capacities, rates and efficiencies; 3) crop characteristics relative to water use and the patterns of water use; 4) climate and environmental effects on crop water demand and irrigation performance; and 5) economic benefits. In the near term, extension educational and demonstration programs can provide irrigators the necessary confidence and knowledge to integrate SIS successfully into their total farming system. Equally important, such educational and demonstration programs will also help train consultants, conservation district staff, and electric utility and other agency personnel in climate-plant-soil-irrigation interactions and proper scheduling techniques and processes so they can work more effectively with growers. In addition, an increasing number of farmers and their children are college-educated, many with advanced degrees, and these individuals are more open to technological approaches to farming than earlier generations.

The technical approaches to SIS are complex because they must be based on many factors related to crops, soils, climate, irrigation method and management objectives as well as local experience with constraints imposed by the water delivery system. In addition, generalized SIS procedures must be tailored to each situation since many of these factors are site-specific. SIS services must adequately integrate and support other farm management decisions perceived by growers to be more important than the irrigation decisions. To be successful in the long term, educational SIS programs must demonstrate the increased value of a range of improved farming practices, such as precision agriculture, that are supported by scheduling. This complexity generally requires consultants and others (e.g., specific employees of large corporate farms) to provide tailored SIS services since most agricultural producers do not have the time or expertise. Unfortunately, many consultants also lack the necessary knowledge to advise irrigators properly on these subjects. Nevertheless, large farming enterprises are more likely to adopt SIS practices because they are often better capitalized and generally more willing to make long-term investments in technology and training.

Remarkable progress has been made in recent years on sensor technologies and automation suitable for SIS, and the diversity is enormous. The economic and environmental incentives as well as the educational level of the farmer will dictate which technologies will be adopted for more accurate scheduling. These devices and tools must be tested and evaluated for use in specific situations, and the new information made available to growers, utilities, private consultants, and other interested parties for inclusion in on-farm SIS programs.

It is estimated that more than 300,000 acres in Washington currently use some aspects of SIS. The successes of past SIS education and demonstration efforts in the region have added to the general perception that SIS may actually be a beneficial and requisite practice rather than an inconvenience. The future availability of low-cost soil/plant sensors, currently unavailable, are crucial to expanding SIS adoption.

4.2.2 Weather Networks

Successful implementation of SIS requires the availability of a network of weather stations that provide timely climatic data for predicting crop water use. Two agricultural weather networks in the Pacific Northwest currently have fully instrumented stations. These networks must be maintained to support both SIS and integrated pest management programs that reduce agrichemical usage. Because of significant microclimate differences between the larger scale stations and farms, some growers have installed their own weather stations to assist in frost protection and pest/disease control programs.

AgriMet is a satellite communications-based network operated by the USBR out of Boise, Idaho. AgriMet provides climatic data at 4-hour intervals from sites near the Washington communities of George, Odessa, Lind, Goldendale, Harrah, LeGrow (on the Snake River near Burbank), and Omak, and in Oregon near Hermiston, Hood River, and Echo).

The second weather network is the PAWS operated by WSU Cooperative Extension out of WSU-Prosser. It is a network of 59 real-time weather stations primarily located in the irrigated areas of the Columbia Basin and Yakima Valley. Stations are also located in the Wenatchee and Omak drainages and a few stations are on the west side of the Cascade Mountains. All of these stations collect 15-minute data and communicate these data to the base station either once an hour over an rf transmission network or over the Internet. During the spring and fall, some of these stations transmit data at half-hour intervals to assist growers in frost protection.

4.2.3 Self-Propelled Center Pivot and Linear Move Irrigation

A center pivot or lateral move system basically consists of a pipeline (lateral) mounted on motorized structures (towers) with wheels for locomotion. A center pivot machine rotates around a "pivot" point in the center of the field, whereas a lateral move machine travels along a straight path and has a separate guidance system. Sprinkler outlets are installed on the top of a pipe supported by steel trusses between adjacent towers. The towers are usually from 30 to 60 m (90 to 200 ft) apart, and each tower has a 1-hp motor and sits on two large rubber or steel tires.

In the United States, approximately one-third of all irrigation, or about 60% of all sprinkler-irrigated lands, is by self-propelled irrigation systems, mostly center pivots. This is about 125,000 machines on approximately 7.9 million hectares (19.5 million acres), or about 29% of the total irrigated area., In Washington, center pivots account for more than 25% (about 190,000 out of 810,000 hectares) of the total irrigated lands, mostly in the Columbia Basin. These sprinkler irrigation systems have allowed agricultural development of "marginal" lands in central Washington unsuitable for surface irrigation, because of their mostly light sandy soils and large variations in field topography. These conditions are also typical of much of the potentially irrigable lands of the Hanford Site.

Worldwide use of these very adaptable water application methods has grown in recent years due to their 1) potential for highly efficient and uniform water applications, 2) high degree of automation requiring less labor than most other irrigation methods, 3) large areal coverage, and 4) ability to apply water and water-soluble nutrients economically over a wide range of soil, crop, and topographic conditions. For these reasons, center pivot irrigation in the United States increased by more than 50% from 1986 to 1996.A standard 50-hectare(125-acre) center pivot system will cost from $35,000 to $45,000, excluding land and water supply development costs. Water development costs depend on the source of water and power (i.e., electric, diesel or natural gas). Generally, the largest annual costs for these machines are for power or fuel to pump water.

Because center pivot and lateral move systems operate semi-automatically, it is relatively easy to manage soil water levels carefully across a field. Almost all crops including sugar cane, orchard and vine crops, and more traditional field crops such as maize, potatoes, small grains, alfalfa, and vegetables have been successfully irrigated with center pivot water application systems under a wide range of conditions. Some center pivot irrigated crops require special cultural practices such as planting in circles or using small pits or reservoirs in the furrows to facilitate infiltration on heavy soils and prevent surface runoff. Application efficiencies higher than 80% are possible depending on management and a properly designed installation for the site. Center pivot and lateral move systems have the potential to be more than water application devices. They also provide an excellent vehicle to apply some chemicals and many fertilizers to match plant requirements exactly. In some areas of south-central Washington that have very light soils, as much as 80% of all nitrogen fertilizer used is applied through the center pivot system. Substantial crop quality and pest control benefits may accrue when using this method for applying chemicals.

In addition, center pivot systems provide an especially suitable platform on which to mount various types of sensors since the lateral system potentially passes over every part of the field every day. Color video and infrared and reflected wavelength specific sensors could be combined and coupled with pattern recognition software and GPS for early detection of stresses due to lack of water or nutrients, disease, and insects as well as potentially identify various weeds and other problems.

4.2.4 LEPA Systems

A special adaptation of self-propelled technology is the Low Energy Precision Application (LEPA) method that can be installed on both center pivot and linear move systems. LEPA has "drop" tubes spaced about every meter that extend to the soil surface where a low pressure bubbler is attached in place of a sprinkler. Water is applied directly to the furrow, minimizing evaporation losses because the canopy is not wetted. Although initial capital costs are higher than standard systems, with the right soil, topography, and management, these systems can be very efficient (e.g., 95-98%). Soil evaporation is generally less than 2% with alternate row irrigation, although runoff may be as much as 50% with poorly designed and operated systems. Wind drift losses also are eliminated. The best results with LEPA have been obtained on heavier clay soils, and use has been limited in the Pacific Northwest (used mostly on mint and alfalfa with shallow furrows) because of the light soils with poor lateral spreading.

Crops are usually planted in a circle so that the drops do not damage plants. Sometimes a canvas "sock" or other fabric energy dissipation device is used to prevent soil erosion in the furrows. A machine such as the Dammer-Diker™ is often used with both LEPA and regular center pivot and linear move application techniques to create small reservoirs that store water until it has infiltrated on heavy or steeply sloping soils. Typical quarter-mile-long (400 m) LEPA systems have from 350 to 450 heads. These systems could also be improved using precision irrigation technologies.

4.2.5 Precision Irrigation with Self-Propelled Irrigation Systems

The goal of irrigation designers is to have the most uniform water application pattern possible along the entire length of the center pivot or linear move, which is not necessarily ideal for crop quality and the environment. For example, our research and that of others (Evans and Han 1994; Han et al. 1995; Mulla et al. 1996; Mallawatantri and Mulla 1996) has shown that, in grossly simplified terms, about 75% of leaching occurs in about 25% of the area in many center pivot irrigated fields in the central Pacific Northwest.

Self-propelled irrigation systems such as center pivots and linear moves are particularly amenable to site-specific approaches because they are automated and cover a large area with a single lateral pipe. Microprocessor-controlled center pivot and linear move irrigation systems provide a unique control and sensor platform for economical and effective precision irrigated crop management. These technologies have made it potentially possible to vary agrichemical and water applications to meet the specific needs of a crop in each unique zone within a field to optimize crop yield and quality. There is less impact to the environment and reduced costs for input water and chemicals. The criteria for managing precision water and chemicals with these self-propelled systems is currently being developed by numerous universities, government research groups, and industry, and is expected to be commonly available within five years.

Despite the inherent high-frequency and fairly uniform applications of self-propelled center pivot irrigation systems, considerable yield variations still exist that are often attributed to spatial variability in soil water holding capacities and related nutrient availability. Variations in water availability across a field result in a farmer needing to 1) ensure that areas with the lowest water holding capacity maintain adequate water levels, 2) manage the whole field based on average soil water depletions, or 3) avoid overirrigation in wettest areas. All of these cases will cause overirrigation or underirrigation of some areas because current center pivot systems cannot differentially irrigate based on varying soil and plant factors within a single field. Some chemical leaching below the root zone, surface runoff, and potential yield decreases may occur in different areas under each management practice.

Thus, it is obvious that having high water application uniformities across an entire field is not necessarily the best in terms of crop quality and the environment. For example, research at WSU and the research of others has shown that, *in grossly simplified terms*, that about 75% of the leaching occurs in about 25% of the area in many center pivot irrigated fields in the central Pacific Northwest. It is evident that the ability to more precisely manage small areas of the field will be necessary to reduce groundwater degradation. *Therefore, the next advances in center pivot and lateral move irrigation will involve being able to vary water and chemical applications along the length of the pipe depending on its position in the field* (Evans and Harting 1999).

Center pivots are especially suitable for site-specific water application because one pipeline and 100+ sprinklers can irrigate 50+ hectares (125 acres). Automating a sprinkle irrigation system for precision water applications requires the ability to control the net application rate from each head individually depending on its location in the field. In addition to improved water management and reduced leaching, another obvious advantage of automating individual heads is that the very high application depths near the pivot point can be reduced to levels matching the rest of the system by using larger, non-plugging heads with better water distribution characteristics. Reducing water applications near the pivot point would also reduce the incidence of fungal diseases. With appropriate sensors, software, feedback, and control systems, irrigation efficiencies of 85 to 95% are possible with precision irrigation using center pivots. Most water losses would be from evaporation and wind drift. Including precision irrigation hardware and control software adds about $250 per hectare ($100 per acre) to the cost of the machine. Agronomic input and monitoring equipment to support management decisions also will increase costs.

4.2.6 Microirrigation Technologies

Drip irrigation, also called trickle irrigation, bubblers, and localized small microsprinklers, microspinners and microsprayers are collectively referred to as microirrigation. Microirrigation includes any localized irrigation method that slowly and frequently provides water directly to the plant root zone. Applying water slowly at discrete locations at low pressure and irrigating only a portion of the soil volume in the field can result in relatively low-cost water delivery systems that divert less water than other irrigation methods. Drippers and bubblers are designed to apply water at atmospheric pressure, whereas microsprinklers apply water from about 50 to more than 250 kPa (7-40 psi).

Microirrigation has the potential for precise, high-level management and is an extremely flexible irrigation method to design. It can be adapted to almost any crop and climatic zone. Microirrigation can be used over a wide range of terrain conditions, and it has allowed irrigated crop production to expand into areas with problem soils (either very low or very high infiltration rates) and poor water quality that could not be used with other irrigation methods. It can be installed as either a surface or subsurface water application system. Application efficiencies above 90% are readily possible under good management with well-designed systems. These systems can cost from $1200 to $3700 per hectare (from $500 to $1500 per acre) depending on the field size and crop.

Microirrigation can be used on most agricultural crops, although it is most often used with high- value specialty crops such as vegetables, ornamentals, vines, berries, olives, avocados, nuts, fruits, and greenhouse plants. In many cases, it can also be used economically for field crops, golf greens and fairways, cotton, and sugar cane. Microirrigation is used almost exclusively on wine grapes in central Washington because of its potential to control soil water levels and influence winter hardiness.

Microirrigation is being used increasingly around the world and in the Pacific Northwest, and it is expected to continue to be a viable irrigation method for future agricultural production. With increasing demands on limited water resources and the need to minimize the environmental consequences of irrigation, microirrigation technology will undoubtedly be even more important in the future. Microirrigation provides many unique agronomic, water, and energy conservation benefits that address many of the challenges facing irrigated agriculture, now and in the future. Farmers and other microirrigation users (i.e., landscapers and golf course managers) are continually seeking new applications to microirrigation technologies, such as waste water reuse, that will continue to provide new challenges for designers and irrigation managers.

Microirrigation inherently offers tremendous benefits for chemical injection and application. Consistent soil water contents and wetted soil volumes tend to increase the efficiency of plant uptake of many chemicals. Water-soluble nutrients can be injected to match crop requirements closely, increase efficiency of nutrient use, and reduce costs. Labeled systemic pesticides and some soil fumigants also may be injected with high efficacy.

Any irrigation system must be compatible with the cultural operations of a specific crop. Using microirrigation may require adapting to new or innovative cultural practices and even the development of new harvest and tillage equipment. For example, surface lateral lines can hinder traditional harvest operations by requiring pre-harvest removal of the tubing or development of a new harvester and harvesting techniques. Lateral lines can be buried, but this generally requires moving to minimal-tillage or permanent-bed systems for perennial crops.

An in-depth understanding of the unique benefits and limitations of microirrigation systems is needed to design and manage these systems successfully. As with all other irrigation methods, there are definite tradeoffs that impact irrigation scheduling, efficiency, uniformity, ecology, crop responses and economics.

4.2.7 Frost Protection in Orchards and Vineyards

In some years, many plants require at least some level of protection from cold temperature injury (frost protection) in Pacific Northwest fruit growing areas. Cold weather can occur during spring, fall or winter, although most cold protection activities for tree crops occur in the spring to keep buds, flowers, and small fruitlets above the critical temperatures at which they can be killed. On the other hand, it is often necessary to protect Pacific Northwest *vinifera* vineyards from frost in the fall to prevent leaf drop so sugar will continue to accumulate in the berries. Sometimes frost protection is needed on perennial trees (i.e., peaches, apricots) and vine crops. Very often only a few degrees rise in air temperature is sufficient to minimize cold damage. Applying water using under-tree and over-crop sprinklers to protect crops from cold temperature injury is common practice in central Washington.

Protecting orchards and vineyards from frost in spring and fall can require large volumes of water to be available for short periods of time, often creating major physical and legal problems for growers. Typical frost protection with under-tree sprinklers requires about 6.25 $l\ s^{-1}\ ha^{-1}$ or 2.3 $mm\ hr^{-1}$. Over-tree sprinkling is more effective but requires about twice that amount.

Frost protection requires water to be delivered before it is normally required for irrigation, and many canal systems are not ready when frost occurs. In addition, most of the canal and on-farm delivery systems in the western United States are generally designed to deliver water at rates too slow to provide frost protection. They are designed to satisfy the requirements of surface furrow (rill) irrigation (max. delivery 1-1.5 $l\ s^{-1}\ ha^{-1}$ [6-9 gpm/ac] continuous flow to farms based on total cropped area), which is also adequate for standard sprinkle systems. These flows are usually combined and used to irrigate smaller areas ("sets"), often at rates above 6.3 $l\ s^{-1}$ or 5.3 $mm\ hr^{-1}$ (100 gpm /ac or 0.21 in/hr). Water use is rotated over several days to cover the entire cropped area. For frost protection, many growers are drilling wells and building large ponds to hold supplemental water or unused allocations.

Water may be required for frost protection over 4 to 6 weeks in the spring. Growers may operate their systems from 20 to 30 nights for 6 to 10 hours per night in a frost protection season. As much as 250 to 500 mm of water can be applied during a single frost protection season.

Because the water is applied in large amounts at times when trees are using very little, groundwater contamination can result by leaching of chemicals and nutrients from saturated soils. Most of the applied water from frost protection is either runoff or deep percolation.

4.3 Economic Impacts of Irrigated Crop Production

The economic impacts of irrigated agriculture are large. It is well documented that irrigation increases yields and provides stability in food production over rainfed agricultural systems. Irrigated lands constitute less than 17% of the world's cultivated farmland but produce 40% of the total food and fiber.

Table 4.2 presents approximate net returns per hectare for some typical crops grown in the area surrounding the Hanford Site. For example, if 50,000 hectares (125,000 acres) were equally split between potatoes, apples, and wine grapes, the gross return based on representative current prices would be more than $430 million per year. When the economic income/employment multipliers are used, the annual value easily exceeds $1 billion.

Income/employment multipliers of 1.7 are commonly used for irrigation sector impacts. At the state level (1997 data), the total direct agricultural industry employment multiplier generated per job ranges from 1.4 to 2.5 with about 5.4 jobs generated per food processing job. By comparison, the total employment multiplier for the aerospace industry is about 2.3, for the computers and electronics industry from 2.4 to 2.7, for business services 1.7, and for fisheries 1.2.

4.4 Future Pressures for Expanded Agricultural Development

By 2050, world wide demands for increased production of animal/fish protein, food, and fiber are anticipated, despite advancements in crop breeding, genetic engineering, and other technologies. World population is projected to double to more than 12 billion people, straining already stressed agricultural resources. Current world surpluses in many commodities will not last when faced with increasing population, decreasing ocean fisheries, and the rapid loss of productive lands from soil salination and erosion. The production of pharmaceuticals from bioengineered plants and animals will undoubtedly add more pressure on the already limited (and declining) arable land base. In addition, there will be pressure to produce crops that can help reduce the world's dependence on petroleum and be used for chemical plant feedstock.

These external, formidable pressures to increase productivity will necessitate increased investments in irrigation infrastructure in many areas of the world. Intensive greenhouse culture and aquaculture also will be greatly expanded. There will be large economic and social pressures to expand production in areas such as the Pacific Northwest. Agricultural exports will continue to be important.

The most likely large areas for expanded irrigation in the Pacific Northwest are the undeveloped East High areas of the CBP and non-restricted areas within the Hanford Site. Both of these are potentially highly productive food and export capital producing areas. The environmental concerns will be large; however, the favorable growing conditions, high-quality (low-salinity) abundant water supplies, and low soil salinity make the Pacific Northwest, from a world perspective, a very desirable region for economically sustainable expansion of agriculture.

The economics of developing each area will have to be assessed. The Hanford Site may be less expensive to develop, even though much of the infrastructure is already in place for the East High area, because of easy access to water (surface and groundwater) and power. However, [public? local? regional?] pressure to develop both areas will mount as existing agricultural resources are stretched in the future. Much of any new agricultural development in these areas probably would be private rather than public.

Table 4.2. Estimated Current Yields and Value Received for Selected Irrigated Crops That Could be Produced on Hanford Site Lands Based on Approximate State Averages of Yields (Metric), Prices Paid, and Net Returns Based on Washington Agricultural Statistics Data (Chase et al. 1993)

Crop	Yield/ha	Unit Price, $	Gross, $/ha	Net, $/ha
Alfalfa	13.5 M Tons	97	1,310	230
Apples	100 bins[a]	116	11,600	1,110
Asparagus	4,000 kg	1.25	5,000	680
Sweet Cherries	15.7 M Tons	1,260	19,780	1,490
Concord Grapes	22.4 M Tons	198	4,435	715
Irrigated Wheat	6.8 M Tons	110	750	52
Onions	53.3 M Tons	88	4,690	860
Potatoes	62.3 M Tons	88	5,480	445
Sweet Corn	18 M Tons	92	1,660	198
Wine Grapes	9 M Tons	1,012	9,110	1,560
Average Return			6,382	734

(a) A bin of apples is approximately 450 kg (1000 lbs).

5.0 Viability of Agriculture on the Hanford Site

This section presents the procedures and results of evaluating the potential for agricultural development of the Hanford Site. In general, the site's semi-arid desert steppe climate offers deep soils, long summer days because of the northern latitude, low altitude and its attendant long growing season, good drainage, mild winters, and the easy proximity of high quality, dependable water in the Columbia River.

Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge are significant sources of cold air drainage that will have considerable impact on agronomic and horticultural crops selected to be grown in the Hanford Site because of the danger of cold temperature injury to orchard and vine crops. However, the general winds from the Pacific Ocean coming up the Columbia River Gorge to the southwest during the spring and fall have a large moderating effect on low temperatures throughout a substantial part of the region, making it a very desirable location for high-value orchard, vineyard, and vegetable crops.

The area's suitability to produce high-value crops is evident in the irrigated areas around the Hanford Site, which are primarily devoted to producing high-value, high-yielding fruit and vegetable crops. According to the 1997 Census of Agriculture, 4% of the crops produced in the United States are fruits and vegetables, but they account for more than 30% of the total farm income. Lands released for irrigated agriculture in the Hanford Site undoubtedly would also produce high-value crops that would have a major impact on the region's economy since soils and climatic conditions are similar.

Any irrigated agricultural development of the Hanford Site will undoubtedly be integrated with wildlife and ecosystem reserves and permanently restricted disposal or old reactor sites. However, making the very big assumption that water rights and environmental concerns will not be overpowering issues, three different scenarios may be envisioned for future irrigated agricultural development of the Hanford Site. These are: 1) small acreages (< 10 hectares [20 acres]) primarily used for pasture and small home gardens with most of the income from off-site sources, 2) large-scale intensive commercial agricultural developments similar to the privately developed large corporate farms that pump water directly from the Snake and Columbia rivers, or 3) a combination of the two. The large scale agriculture might also be integrated with highly intensive production in greenhouses (irrigated) and/or aquaculture.

The small farms and ranchettes near Benton City and the West Richland area probably would be typical of the types of small acreage (suburban) farming operations on the Hanford Site, if permitted. Currently, these 0.5 to 10-hectare (1 to 20-acre) operations are mostly devoted to pasture, small gardens, and landscaping, with a few small vineyards and orchards. Irrigation efficiencies are generally quite low because of poor water management due to a number of factors, but mostly due to the lack of time by the owners because of other commitments and the fact that their livelihood does not depend on the production efficiency or profitability. The poor irrigation efficiencies tend to result in excessive water moving toward the groundwater and the leaching of chemicals from septic tanks, fertilizers, and other soluble materials used on the properties.

The national trend in commercial agriculture is toward larger farms and vertical integration of farming operations with processing and marketing due to rising input costs, declining commodity prices, and the cost of environmental regulations. Global competitiveness and the regional economics of agriculture suggest that this pattern would also be the norm for future large-scale commercial agriculture at the Hanford Site.

If the Hanford Site was developed for irrigated agriculture today, it would likely consist of large, vertically integrated farming enterprises using center pivots and microirrigation techniques. Based on current trends, the most probable crops grown on the Hanford Site would include:

1. Alfalfa, pasture, and forage crops
2. Premium varietal wine and juice (Concord) grapes
3. Tree fruits such as apples, pears, and sweet cherries
4. Field crops such as dry beans and feed corn
5. Sugar beets
6. Vegetables crops such as potatoes, asparagus, sweet corn, carrots, and onions.

Groundwater flow direction under the Hanford Site is predominately from west to east. As water is removed from the unconfined aquifers (Hanford and Ringold), groundwater flow velocities may decline in some regions of the acquifer and perhaps reverse, greatly slowing or even reversing the migration rate of various contaminant plumes, possibility allowing more time for treatment and/or radioactive decay before they reach the river systems. Excessive groundwater pumping in the interior of the Hanford Site and/or locating pumps near the river could enable surface water to be drawn directly from the Columbia River into the acquifer and the wells.

Groundwater development will require careful management and implementation of specific water withdrawal strategies (spatial and temporal distribution of the volume of pumped water) with water applied to agricultural crops. Carefully managed groundwater use potentially can be part of the contaminant control and treatment programs. Irrigation diversions should probably be a mix of surface and groundwater supplies. One scenario is that areas directly above contaminant plumes and between the plumes and the river would use river water (or deep wells in the confined aquifers), while areas to the sides could use shallow groundwater to manage hydraulic gradients. The mix of surface water and shallow groundwater pumping might avoid potential contamination of crops and keep contaminated groundwater plumes away from the river. This type of program would need to be supported by monitoring and sophisticated computer modeling of the system.

A realistic potential development scenario involving contaminated groundwater will depend on: 1) stewardship or security of the waste disposal sites, 2) health and environmental considerations to protect people in the area, and 3) use of the water in unconfined aquifers in light of contaminant movement for domestic, industrial or irrigation uses. Based in these criteria and the undesirable consequences of poor irrigation efficiencies common to most small farms/ranchettes, it was decided to base most of this analysis on only the second option of large commercial agriculture (no greenhouses) that is typical of the region.

5.1 Analysis

Determination of reasonable future agricultural uses was based on review and analysis of existing data, maps, reports and observations from DOE, Pacific Northwest National Laboratory (PNNL), WDOE, USBR, USDA-Natural Resources Conservation Service, WSU Cooperative Extension, local governmental agencies, and other sources. No new data were collected as part of this study. The analysis of potential agricultural land use patterns for the Hanford Site was generated using a GIS to collect and compare existing data.

Existing electronic digital elevation maps (DEM), digital line graphics (DLG), digital orthoquads (regional satellite and aerial photographs that have been processed to include coordinates) and other available data on soils, crops, field sizes, climate, and housing information were entered into a GIS data base. Topographic data were based on digital elevation maps in the GIS to extract information (layers) on slope, aspect, and elevation (see Figure 2.2).

Land use data were collected by viewing the orthoquads, digitizing, and entering them into the GIS data base on current land use. Land use data were somewhat verified by limited field inspections to check crop types. A 1996 baseline was selected for the land use comparisons because it was the latest date for which many data were available including orthoquads and the 1997 U.S. Census of Agriculture information.

The orthoquads covering the study area were either purchased from the U.S. Geological Survey-Earth Resources Observation Systems (USGS-EROS) Data Center or obtained from the USDA-NRCS and entered into the ArcView GIS program. Crop types and other types of land use were digitized from the orthoquads although some ground verification of crops was required. Some land use information on Franklin and Grant Counties was provided in ArcView format by the Franklin Count Conservation District and the Grant County Conservation District, respectively. The land use data were used to help create GIS layers on existing land use.

Soils data were entered into the GIS using digital copies of the existing Hanford soil survey (Hajek 1966) and USDA Soil Surveys for Grant (1984) and Franklin Counties (draft information 1999). Parts of Adams and Benton County soil surveys (1967 and 1971, respectively) were digitized and entered into the GIS. The soil classifications were merged, and a GIS soils layer was developed.

The GIS data bases were used to develop the summary of characteristics of irrigated and rainfed agriculture in the surrounding area from Royal Slope, Wahluke Slope, Cold Creek, the north slope of Rattlesnake Mountain, the southwest corner of Adams County, and the western portions of Franklin County. GIS layers of soils, slope, aspect, topography, land use, etc. were used to generate areas of common characteristics. These characteristics were used in conjunction with other reported data and observations to evaluate various land use scenarios for the Hanford Site based on comparisons from surrounding agricultural areas.

Comparisons of land use by soil classification and topography were made by overlaying the GIS layers. The information was then sorted by crop type, soil classification, aspect, slope, and elevation.

Slope is given in percent gradient as a length (i.e., meters) per 100 of the same unit lengths. Aspect, also often called exposure, is the direction is which the land is primarily facing. This is normally presented as a circle in degrees from true north (0 to 360). For example, an area that has a southern exposure, would have an aspect of approximately 180 degrees, whereas a northern exposure would be 0 or 360 degrees.

No information was directly collected on the types of irrigation systems used. However, the assumptions and much of the discussion is based on experience and current published data on the various types of irrigation systems used in central Washington and is not specific to the study area. It was assumed that the types of irrigation systems in the study area followed the regional distributions.

5.1.1 Selection of Lands for Comparison

It was assumed that basing future land use on the Hanford Site and other areas in central Washington on current agricultural development was reasonable and appropriate. It was also assumed that the current trend toward large field sizes will continue, and the management capability of growers will be substantially improved in 50 years.

Yakima Project lands were not used for comparisons in this study because the relatively small field sizes, exposures (slope, topography, and aspect) and cropping patterns are not representative of expected potential agricultural situations in the Hanford Site. CBP lands were used as the major source of data for developing land use scenarios for this project due to cropping patterns and other physical similarities to the Hanford Site. In addition, much of the CBP irrigation development is more recent than the Yakima Basin Project lands and reflects modern agricultural development strategies: they are highly capitalized with large fields and professional managers.

The Royal Slope area of the CBP has similar aspect, topography and slopes common to many areas of the Yakima Valley, but its more recent development is probably more indicative of the types of development that would occur in the Hanford Site. The Wahluke Slope (Mattawa) is a particularly appropriate example of the expected types of development because of its proximity and recent irrigation development. In addition, the Wahluke Slope has similar geology and pumps from the same unconfined aquifers. Consequently, the South District of the CBP contains most of the lands used for comparison in this study to predict likely potential future agricultural land use patterns on the Hanford Site.

5.1.2 Summary of 1996 Land Use

Land use was summarized by broad categories related to crop type as presented in Table 5.1. Some, such as the round center pivot irrigated fields were obvious from the aerial photography and were known to produce field crops although the exact crop was unknown. Center pivots are used for field crops such as potatoes, sweet corn, and alfalfa. They are very seldom used on tree and vine crops in the inland Pacific Northwest although center pivots are used on orchards and vineyards in other areas of the world. Orchards and vineyards could be distinguished from the orthoquads, but whether they were apples or cherries, wine (vinifera) or Concord grapes could not be determined. Field visits were made to verify crops in certain situations. For example, it was necessary to determine whether a vineyard was wine grapes or Concords because of the substantial water use differences (2X) between these crops.

Table 5.1. Summary of Study Area Statistics on 1996 Agricultural Land Use

Category	Acres	Hectares
Center Pivot Irrigated Field Crops	139,403	56,416
Other Field Crops	148,252	59,998
Wine Grapes	5632	2279
Orchard	51,311	20,765
Feedlots	511	207
Concord Grapes	578	234
Towns (Urban)	23,271	9418

Field crops are irrigated by center pivots and other sprinkler systems and some are surface irrigated. Orchard and vine crops are typically irrigated by sprinkler and microirrigation methods. Microirrigation and other pressurized water application techniques are more appropriate for vine and tree crops, in fact, the rigorous water management requirements of wine grapes in this region make microirrigation the system of choice of most growers. Figure 5.1 shows current land use on the Hanford Site and surrounding agricultural areas. It is evident that center pivot irrigation is a major water application method.

Analysis of crops based on soil type, aspect, and percent slope shows a consistent pattern of most irrigated production occurring on silt loams, sandy loams, and loamy sands. Because of the regional stratigraphy, the majority of crops are produced on southwest, south, and west sloping lands (a factor that makes the region so suitable for orchard and vineyard crops). In addition, most crops are grown on slopes of less than three percent, although a substantial portion of the orchard crops are on slopes of 10% or less because of cold air drainage concerns. Much of the lands within the Hanford Site have the same characteristics and would be expected to produce similar crops with similar yields to the surrounding lands.

As noted, the majority of irrigated agriculture in the study area is located on loamy sand, sandy loam, fine sandy loams, and silt loam soils. These soil types are common on the Hanford Site (Figure 2.1). Table 5.2 summarizes land use by soils for the study area. Some relatively small areas of cobbles and stoney soils occur on the Hanford Site; however, as seen in Table 5.2, these are seldom farmed because of the very low water holding capacities.

Slope and aspect are important considerations in the long-term production of orchard and vineyards in central Washington. Center pivot irrigation systems are not recommended for use on general slopes exceeding 15%. Figures 5.2 and 5.3 show the slope and aspect characteristics of lands within the study area that includes the Hanford Site. As can be seen, numerous similarities exist between slope and aspect conditions on the Hanford Site and the surrounding agricultural lands. Soil types are also similar.

Figures 5.4 and 5.5 graphically summarizes the percent slope of the study area and the Hanford Site, respectively. While the study area includes the Hanford Site, there is substantially greater area in the study area. The Hanford Site has lower general slopes, which is desirable for irrigated agriculture because it reduces soil erosion and decreases pumping costs.

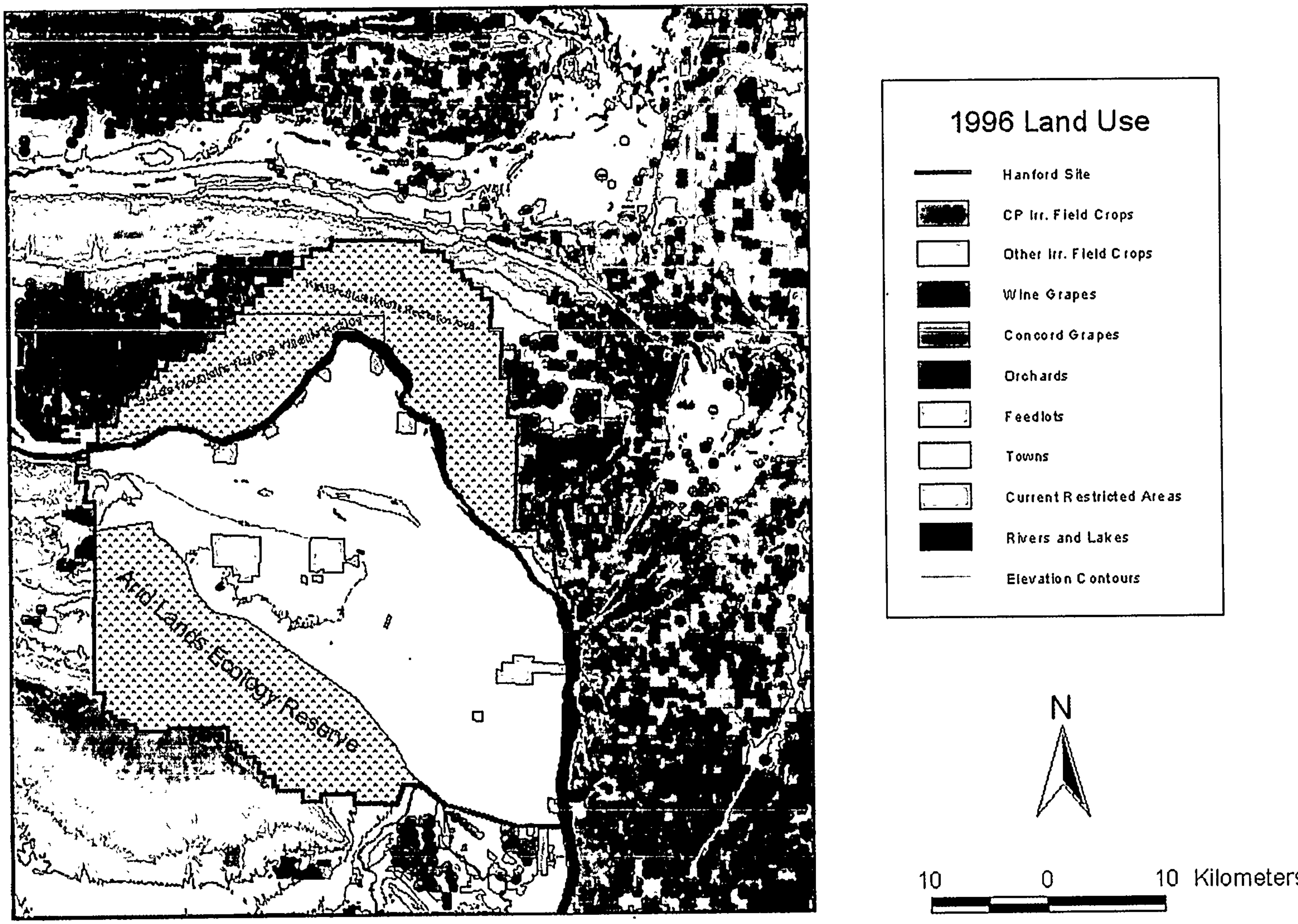

Figure 5.1. Land Use on the Hanford Site and the Surrounding Area in 1996. The white areas are range land in dry land wheat production.

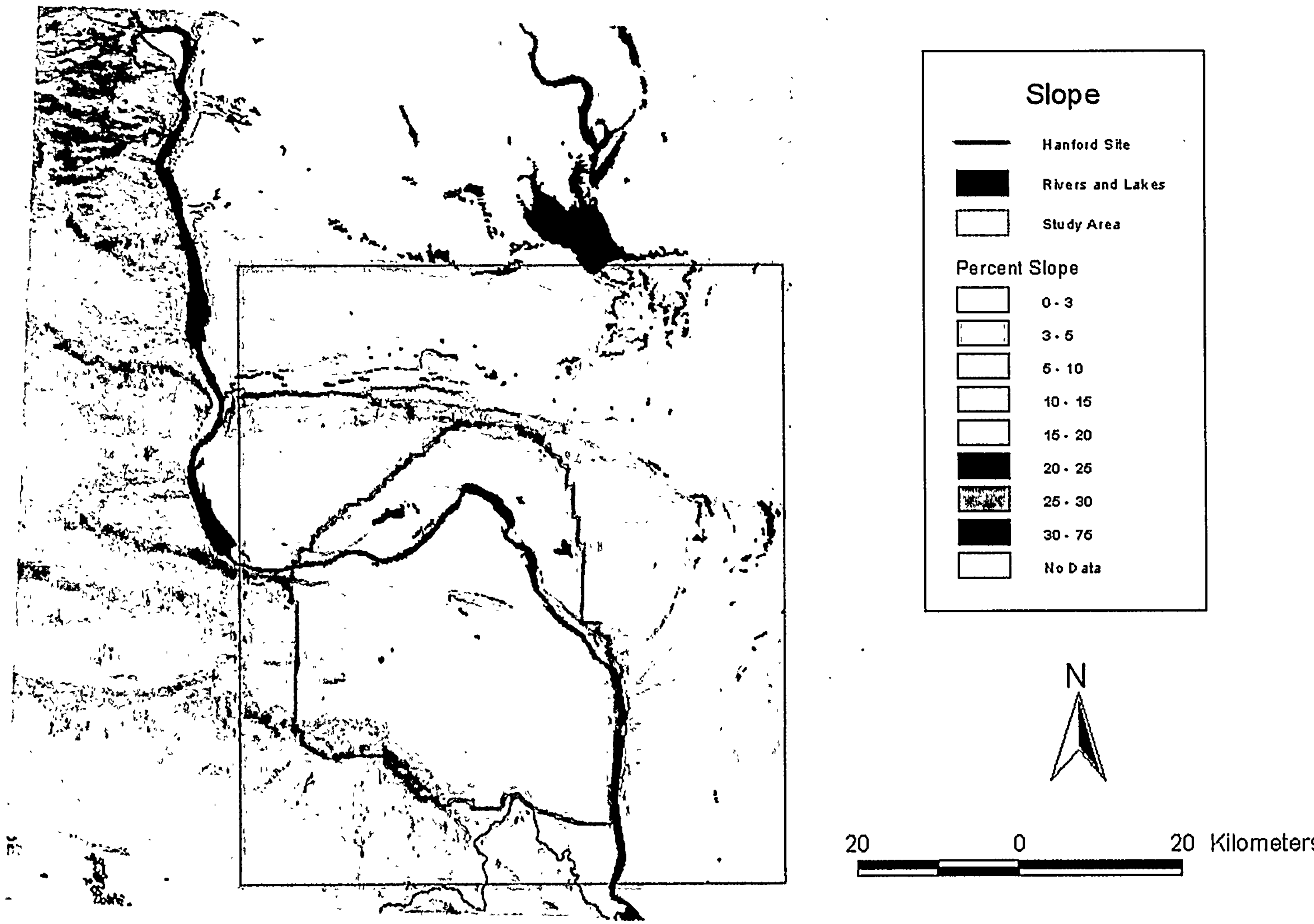

Figure 5.2. Map Showing the Slope Analysis of the Study Area Including the Hanford Site

Table 5.2. Summary of Irrigated Agricultural Land Use in the Surrounding Areas by Soil Types Found Within the Hanford Site

Soils	Hectares				
	Center Pivots	Trees	Wine Grapes	Concord Grapes	Field Crops
Loamy Sand	33,403	4588	189	48	6433
Sand	6077	580	8	0	836
Fine Sandy Loams	12,486	320	10	0	146
Sandy Loam	28,612	6750	342	185	25,940
Silt Loam	7953	5530	1048	0	15,666
Cobbly Loam	74	15	0	0	3
Cobbly Sandy Loam	619	165	114	0	484
Stony Silt Loam	32	22	0	0	92
Cobbly Silt Loam	103	149	77	0	10
Stony Loam	242	0	0	0	28

Figures 5.6 and 5.7 graphically summarize the aspect characteristics of the study area and the Hanford Site, respectively. When examined in conjunction with Figure 5.3, it is obvious that aspect would not deter future agricultural development of the Hanford Site. For example, the Hanford Site has numerous similarities to the very productive Wahluke Slope area.

5.1.3 Recharge Rates

Under irrigation, recharge to the groundwater depends on the application efficiencies of each irrigation and the uniformity of water applications, which are largely functions of system design, management, and environmental conditions (e.g., wind). Recharge is greatly affected by soil texture and soil chemical properties as well as crop cover and rooting extent. Deep percolation losses (artificial recharge) will vary by crop because of management and ancillary uses of the irrigation systems such as for frost protection or agrichemical applications applied for cultural reasons even though soil water levels may already be high.

Application efficiency is defined as the ratio of the average depth of irrigation water infiltrated and stored in the root zone available for plant use to the average depth of total irrigation water applied, expressed as a percentage. Application efficiencies will change during the irrigation season, and calculated values may even exceed 100% under soil water deficit conditions. Dividing the required depth of water to be applied to refill the root zone by the decimal value of the application efficiency will give the required diversion of water to the field.

Applied water may be lost by surface runoff, deep percolation, and soil evaporation (typically 2-5%). Surface runoff may be as much as 50% of the applied water with poorly designed and managed systems. However, surface runoff from a field often collects in small off-site depressions and drainage ways, and some of the runoff returns to the rivers and streams. Much of it infiltrates the soil and contributes to the

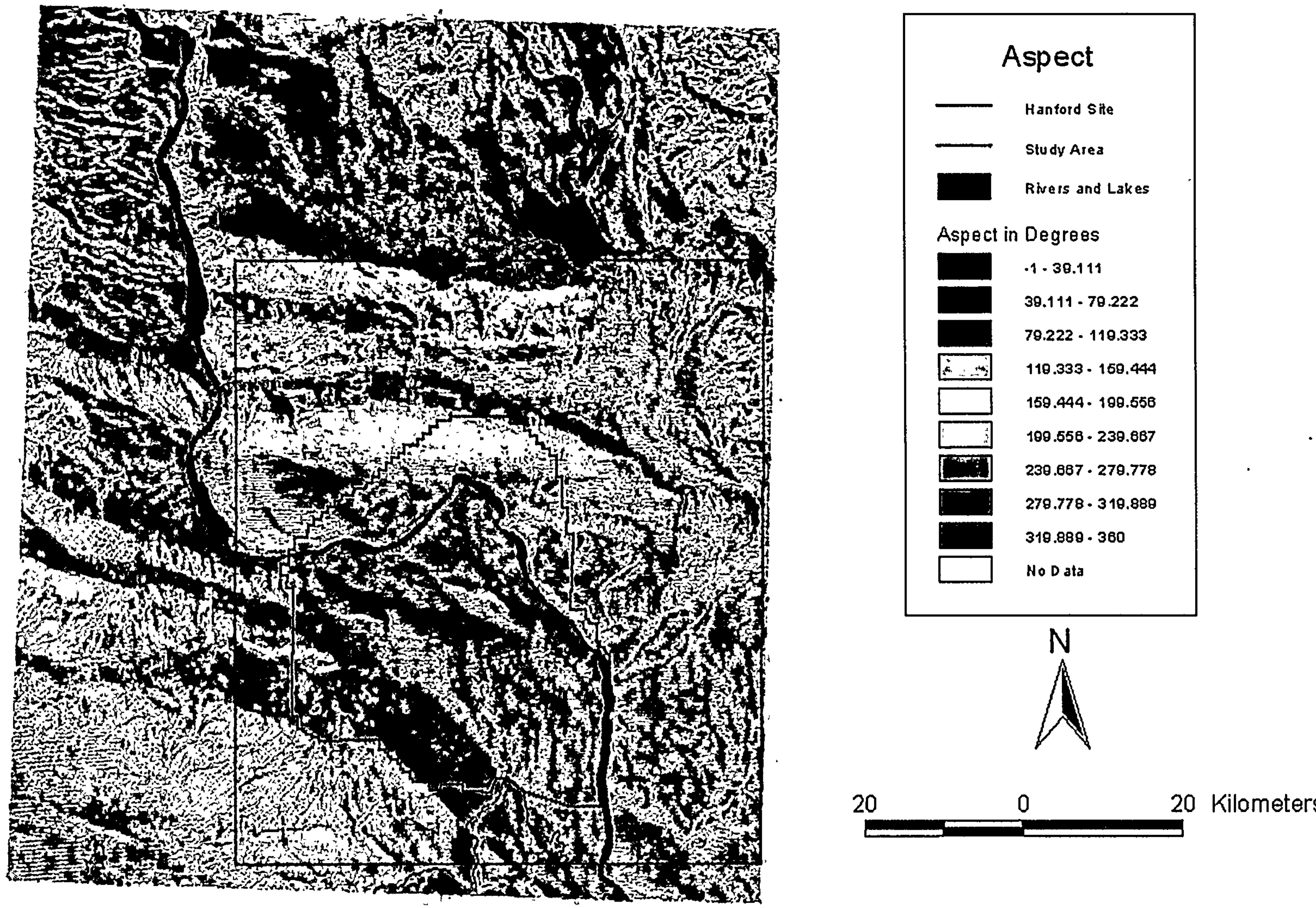

Figure 5.3. Map Showing the Aspect Analysis of the Study Area Including the Hanford Site

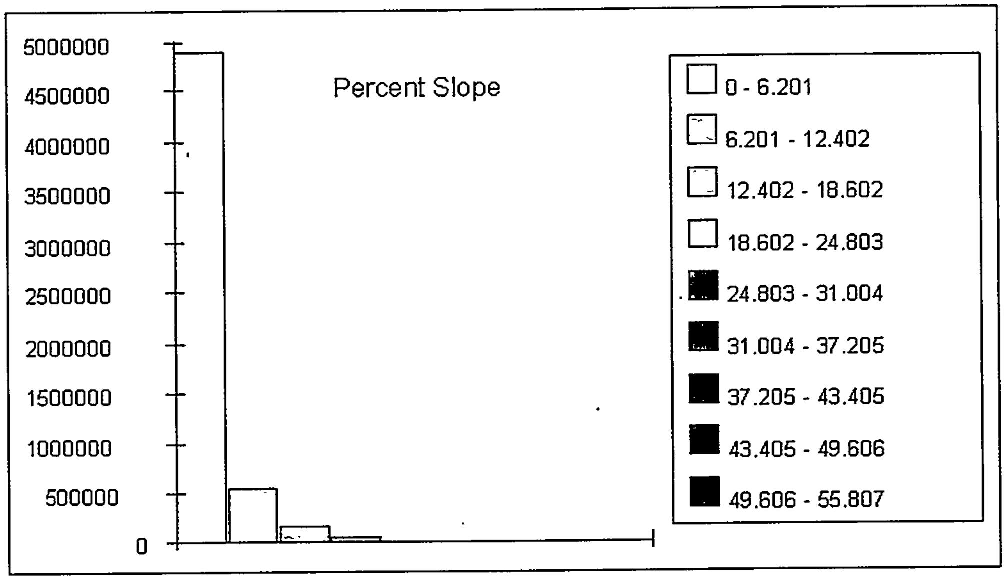

Figure 5.4. Summary of the Slope Characteristics in Percent Slope for the Study Area

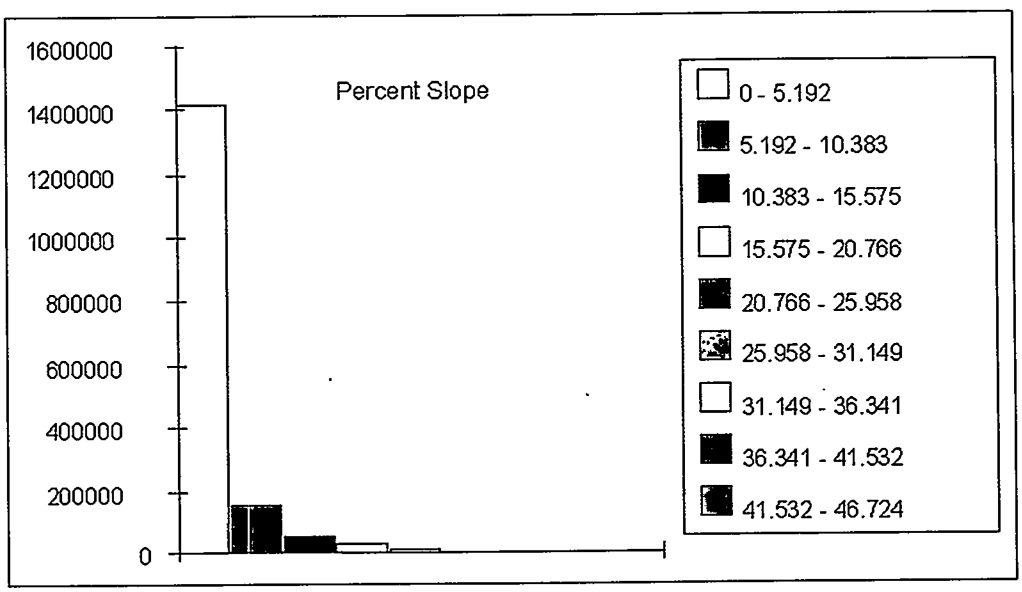

Figure 5.5. Summary of the Slope Characteristics in Percent for the Hanford Site

deep percolation towards the groundwater in the locale. Small wetland areas are often indications of where sustained runoff has percolated towards the water table. Consequently, estimates of deep percolation from irrigation over a broad areas often combine much of the runoff into the recharge calculations (i.e., 80% of losses). Since little surface runoff would be expected to return directly to the river on the light, sandy soils on the Hanford Site, this is a reasonable assumption for irrigated development in that

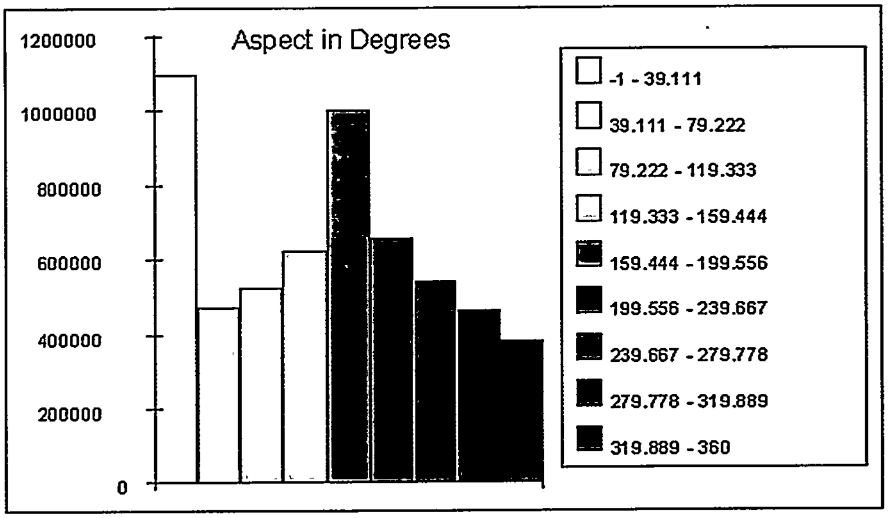

Figure 5.6. Summary of the Aspect Characteristics in Degrees for the Study Area

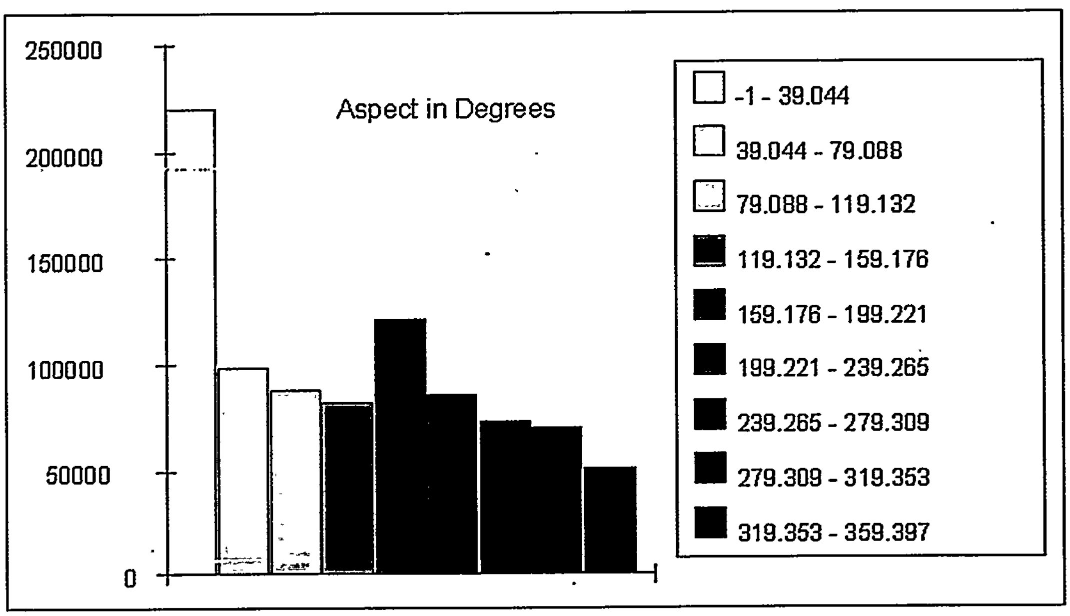

Figure 5.7. Summary of Hanford Site Aspect Characteristics in Degrees from North

area as well. However, estimates of deep percolation losses based on current irrigation practices will probably be higher than what will be the case in 2050 because of growers assumed increased management capability and improved technology.

Some deep percolation is always necessary (generally less than 2% of total annual water application in central Washington) under irrigated conditions to prevent salination of soils (leaching requirement). However, excessive amounts of deep percolation also carry fertilizers and other chemicals towards the groundwater and is a cause for concern.

It is highly probable that any future irrigation development on the Hanford Site would be with pressurized irrigation systems because of the very sandy soils and undulating topography Water supply to fields would be by pressurized pipelines rather than canals or ditches. Thus, any deep drainage losses from the water delivery system would be extremely small and not a major factor except in the infrequent and brief event of a pipeline structural failure.

The average on-farm delivery is about 1.13 ha-m/ha (3.7 acre-feet/ac) to all crops in the CBP. Average annual crop irrigation requirements are estimated at 0.83 ha-m/ha (2.71 af/a) (Montgomery Water Group 1997). This is a difference of about 305 mm (12 in.) in losses, but the percentage of this approximate value that is runoff compared to deep percolation (recharge) is not known since much of the surface runoff is captured and reused.

It is extremely difficult to obtain reasonable values for deep percolation because this is the only value in the water balance that cannot be measured or calculated accurately. Consequently, deep percolation is the term that contains all the errors from the other parameters. Estimates of deep percolation range from less than 25 mm (1 in.) to more than 250 mm (10 in.) per growing season depending on the crop and water management practices. It is known, however, that most of the deep percolation losses occur early and very late in the growing season with very little during peak water use periods in between. Nevertheless, the values for irrigation in Table 5.3 are probably fairly typical for current central Washington conditions during the growing season. These values do not including chemigation, frost protection, crop cooling or other ancillary water applications.

Current estimates of seasonal deep percolation (water lost below the plant's root zone) depend on soils, crop, soil and water salinity, type of irrigation system used, and the level of water management. Deficit irrigation strategies can reduce deep percolation within the growing season whereas using water for frost protection in orchards and vineyards can be a major source of water loss. Properly managed overcrop sprinklers used for crop cooling will have almost no impact on deep percolation; most water is lost by evaporation by design and intent.

Depending on management, center pivot irrigated potatoes tend to have most of their deep percolation occur in the early spring or late fall with very little, if any, during the middle of the summer. Because of the necessary strong emphasis on water management of wine grapes for winter hardiness, wine grapes will have almost no deep percolation (background rates), unless overcrop sprinkling is used for frost protection in the spring and fall.

Table 5.3. Comparative Average Seasonal Application Efficiencies for Various Irrigation Methods and Estimates of a Reasonably Attainable Percent of the Applied Water Resulting as Deep Percolation With Current Technology on Sandy Loam Soils in Washington (assuming irrigation systems are not also used for other purposes)

Method		Application Efficiency		Estimated % of Applied Water as Deep Percolation	
		Range	Average	Range	Attainable[a]
Surface:					
	Furrow (rill)	35 - 60	45	10 - 50	25
	Furrow w/land leveling	50 - 65	60	10 - 40	15
	Furrow w/automation[b]	75 - 80	75	10 - 20	15
	Furrow w/tailwater re-use	75 - 90	85	10 - 20	15
Sprinkle:					
	Hand-move	60 - 70	65	20 - 30	25
	Wheel-move	60 - 70	65	20 - 30	25
	Center pivot/Lateral Move	60 - 85	75	10 - 30	10
	Precision System	80 - 95	90	2 - 10	2
	LEPA	85 - 98	90	2 - 10	5
	Traveling gun	55 - 70	60	20 - 35	20
	Solid set	60 - 80	70	10 - 30	20
Microirrigation:					
	Drip/trickle	80 - 98	90	2 - 20	5
	Micro-sprayers	80 - 90	85	2 -15	8

(a) Percentage of deep percolation attainable under reasonably good current management practices.
(b) Automated surge flow furrow irrigation.

The owners of future suburban-type developments in the Hanford Site would likely insist on irrigation using groundwater sources for at least small portions of their properties. It is highly probable that irrigation efficiencies would still be low. In addition, use of shallow groundwater for domestic purposes, which is typical for such developments, may be difficult because of real or perceived contaminant problems. Water use requirements and distribution are extremely difficult to estimate for this option. If these developments were fully irrigated, recharge rates would be expected to be at least twice that of large-scale agricultural developments.

Deep percolation under furrow (gravity surface) irrigation on the sandy soils and topographic conditions in the Hanford Site will be much larger than presented in Table 5.3. These losses could be reduced somewhat with short runs and surge flow techniques, but these options are not economically competitive with pressurized sprinkler or microirrigation methods.

6.0 Discussion

The current high-value irrigated agricultural production on neighboring lands near Mattawa and east of the Columbia River in Grant and Franklin counties with similar slope, aspect, and soil textures s have clearly demonstrated that a considerable portion of the Hanford Site would likewise be quite valuable for large-scale farming of crops such as potatoes, fruit trees, and wine grapes. Some sloping areas would be especially suitable for orchard and vineyard crops whereas many of the lower elevation areas are appropriate for multi-year rotations of vegetable crops. The high value of these crops (see Table 4.2) would provide the economic ability to adopt advanced technologies and high-level management. Based on current trends and conditions, economics dictate that farm sizes would be large.

It is highly likely that precision agriculture and precision irrigation (center pivots and microirrigation) technologies will be standard operating practices in large-scale agriculture in the future. Portions of these advanced technologies are currently in development but have already demonstrated it is possible to greatly minimize chemical use and deep percolation. However, they will require excellent management, sophisticated control systems, and other resources available in highly capitalized, professional operations. Scientific irrigation scheduling and a supporting network of weather stations must be included.

New advances in microirrigation and self-propelled linear move and center pivot systems will probably have the most promise for future irrigation of field and vegetable crops on new lands like the Hanford site that have light soils and undulating topography. Microirrigation would be most appropriate for tree and vine crops.

The dry climate, long daylight hours, and the ability to control soil water levels throughout the season, make cultivation of specialty crops (e.g., pharmaceuticals, seed crops, herbs, special oil crops) highly likely. The capability to implement exact water and agrichemcial management scenarios to achieve specific quality parameters in a particular crop will allow growers to better respond to economic conditions and produce high-quality crops for niche markets. Pharmaceuticals from bioengineered plants and animals likely will be an important part of the future of agriculture in the region. Likewise, aquaculture may be important considering its intensive nature (small area required), the abundant water supply from the Columbia River, and the potential to apply wastes to nearby agricultural areas economically.

Potential exists to integrate confined livestock feeding and irrigated crop production. With careful management, livestock wastes could be applied to the land as a nutrient source.

Irrigated crops also would be a potential winter food source for migratory water fowl. Other wildlife (e.g., deer and elk) may feed all year on crops and may cause substantial damage to orchard and vine crops. Thus, it may be necessary to compensate growers for some level of damages from wildlife feeding as an incentive for development. Leasing hunting rights to private groups would also help offset crop loss due to wildlife.

Salination of the irrigated soils is not expected to be a problem, but soil erosion could be significant without proper management. Based on a large body of research and experience in the CBP, leveling fields to improve irrigation uniformities is not generally recommended for Hanford Site lands because it would cause long-term soil fertility problems.

Figure 6.1 shows the potentially irrigable lands within the Hanford Site, excluding the wildlife refuges on the north side of the Columbia River, and probable types of crops. Land use is indicated as either most probably field crops or most probably orchard and vineyard based on the land use patterns surrounding the Hanford Site. The areas defined as field crops would probably be irrigated with center pivots and could produce a wide variety of crops. Orchards and vineyards would likely be microirrigated and could be intermixed within the center pivot areas. Likewise, the designated orchard/vineyard areas also could be planted to field crops irrigated with center pivots. The crops produced under center pivots would most likely be part of multi-year potato cropping rotations and not trees and vines.

Analysis of the land use data shows that the total irrigable area (not including buffers) including both the north (wildlife refuge areas) and south side of the river is about 120,380 hectares (297,442 acres). The total (entire site) classified as suitable for field crops is 78,570 hectares (194,143 acres) whereas orchard and vine crops are 14,665 hectares (36,236 acres). Near the northern boundary, 8360 hectares (20,660 acres) is ideally suited for orchard and vine crops. Over the entire site, 27,160 hectares (67,116 acres) was classified as unsuitable for irrigation, not including buffer areas. One kilometer-wide buffers were excluded from all rivers and lakes (20,100 hectares [49,681 acres]) and current restricted areas (16,280 hectares [40,239 acres]). The state and federal wildlife reserves account for 35,740 hectares (88,315 acres).

If the wildlife areas are excluded and just the south side of the Hanford Site is opened for agricultural development (as shown in Figure 6.1), 6300 hectares (15,576 acres) are classified for tree and vine crops and 62,640 hectares (154,775 acres) for field crops. The 25,950 hectares (64116 acres) on the side of Rattlesnake Mountain are classified as unsuitable for irrigation and are totally within the Arid Lands Ecology Reserve (30,910 hectares [76,380 acres]).

6.1 Impacts of Development

A number of unresolved issues will have a large impact on future land use for the Hanford Site. Population growth in the western United States is projected to increase by 30% by 2020 (Western Water Policy Review Advisory Commission 1998). The populations of Washington, Oregon, and Idaho are expected to increase by more than 30% by 2020, which will place additional pressures on the region's water resources for industry, domestic use, agriculture, recreation, and power generation.

A crisis in water demand that continues to worsen has been created by unhealthy trends in aquatic ecosystems and water quality, endangered species regulations, sharp population growth in the region, international and interstate agreements on water allocations, unfilled Native American water claims, and an agricultural economy in transition. Global warming may have a large affect on the availability of future water resources.

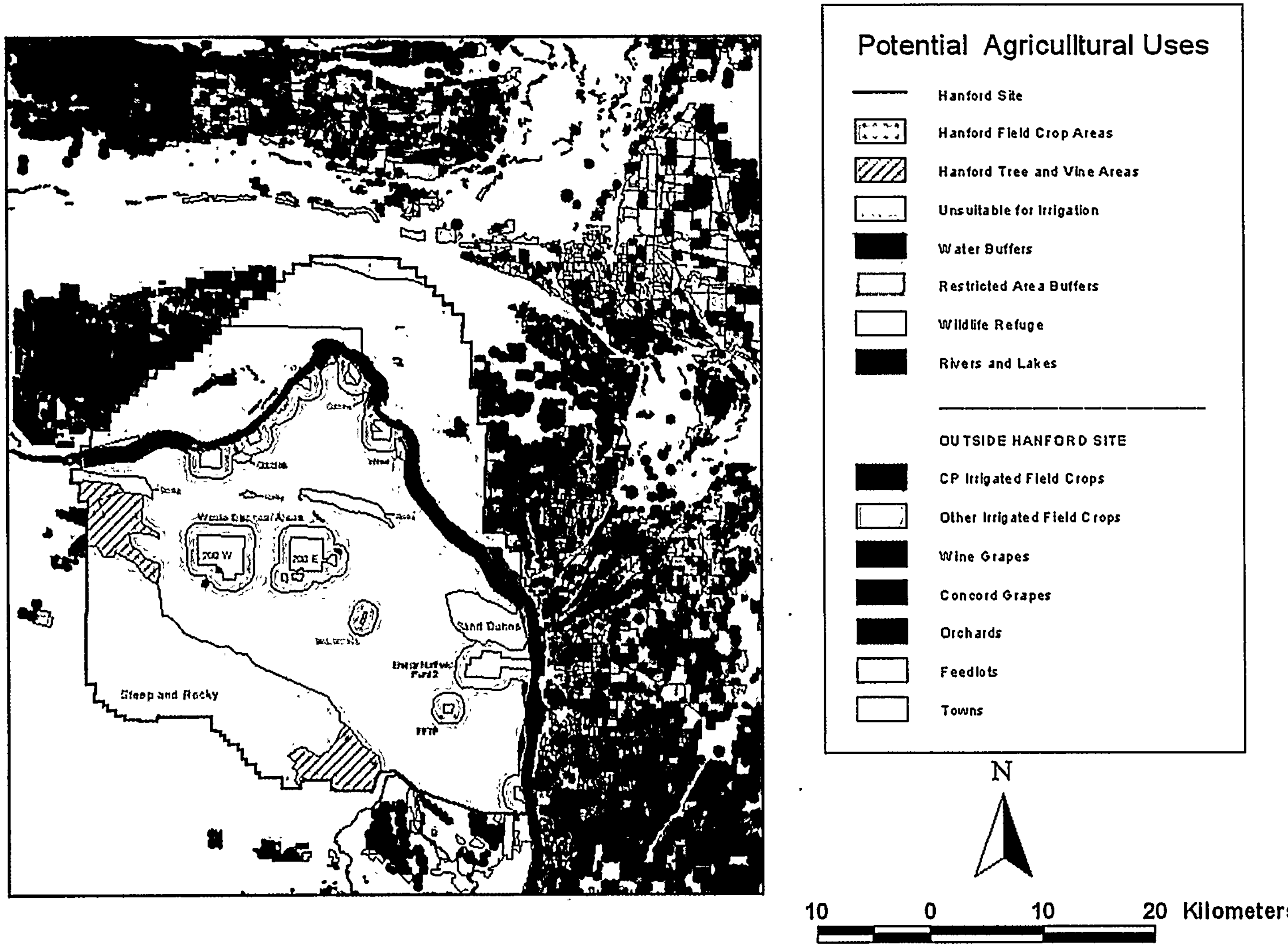

Figure 6.1. Map Showing Potential Agricultural Land Uses on the Hanford Site

Several salmon and steelhead fisheries in the Columbia River system are listed as endangered by the federal government, which will have a huge impact on current and future development of regional water resources. Reduced flows in the river system caused by irrigation withdrawals may have a negative impact on hydropower generation. Any additional future development must consider these and other environmental issues that will arise as well as potential mitigating measures.

Based in the CBP experience, irrigation can increase wetland areas, which would benefit migrating birds and local wildlife. However, increased wetlands would probably not occur under more precise and improved irrigation management. Nevertheless, large-scale agricultural activities would provide a considerable food source and foraging area for migratory and local birds during the fall and winter months.

The Hanford Site is part of the oldest and largest old-growth desert ecology community in eastern Washington. However, the future status of the Arid Lands Ecology Reserve or the wildlife refuge areas were not considered in this study. Ecosystem issues could have a significant impact in which lands might be developed for agricultural uses such as livestock grazing and crops such as wine grapes and orchards.

Migration of deer and elk herds on the Hanford Site will probably not be compatible with irrigated agriculture. They and smaller wild animals and birds would certainly suffer under a small farm/ranchette scenario because of the potential large number of fences as well as abundant dogs and cats, based on the current model. Large-scale agriculture would be more compatible, although it is likely growers would request compensation (under current state laws and regulations) for crop damages caused by the large herds. It is probable that critical areas, defined by county law under the state Growth Management Act as wetlands, areas prone to landslides, and fish and wildlife conservation areas, would be kept as permanent wildlife habitat.

It is assumed groundwater contaminants resulting from past industrial activities on the Hanford Site will still be a problem if and when the site is opened for agricultural or other development in the future. In addition to radioactive materials (i.e., tritium, iodine-129, uranium, technetium-99, strontium-90), significant problems are toxins and other chemicals (heavy metals, trichloroethylene, chloroform, carbon tetrachloride, or any exotic persistent organics such as PCBs, dioxin, etc.) that shouldn't be deposited on agricultural lands. If these contaminants cannot be kept from the applied water, then soil filtration, biological treatment, or other appropriate specific treatment processes may be required before the water is applied to crops. If these industrial contaminants cannot be removed, they must not be applied to any agricultural crop because the perceived implications of unhealthy foods could be transferred to all Northwest crops and result in huge financial consequences. It is entirely likely that water sources would be limited to upgradient unconfined groundwater, the Columbia River, and deep confined aquifers.

6.2 Water Rights

Wallace Stegner (1994) said that "water is the true wealth in a dry land." This is certainly the case in central Washington, with its high-quality, abundant flows of the Columbia River. The control over who gets water at what time for what use is a very emotional issue with huge environmental and economic impacts. The issue of changing the control paradigm of water in the West is a priority of many environmental and conservation groups and is being bitterly challenged by pro-development and agricultural interests.

Water rights in Washington are a mix of prior appropriation and riparian doctrines depending on location. Arid areas east of the Cascades are primarily prior appropriation. Water rights are determined by the Superior Court and regulated (administered) by WDOE. WDOE is also responsible for developing regulatory programs and enforcing water quality laws and regulations.

However, the issue of water rights and the control of water in Washington is in a state of flux. There is little chance that the existing water rights structure will exist when, or if, the Hanford Site is developed for agriculture. The state government is currently proposing sweeping changes to existing water rights law in Washington. Regional water markets based on the true economic value of water will likely appear in many areas and influence water distribution. The federal government is rethinking its water policies and priorities in the western United States, which Congress will undoubtedly act on in the next decade. Endangered species regulations are accused of abrogating state's authority on water issues. Interstate and international agreements combined with societal needs for flood control, navigation, and electrical power will exert strong influences. The courts, politics, and public opinion will shape the final outcome and determine how we manage our precious water resources. Whatever the result, obtaining a reliable and adequate water supply will be crucial for any future economic development of the Hanford Site, agricultural or otherwise.

6.2.1 Hanford Site Water Rights

Section 4.3.3.1 of the Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement (DOE 1999) provided the following statement on water rights in the Hanford Site:.

"The DOE's past and present water withdrawals at the Hanford Site are based on the "Federal Reserved Water Rights" doctrine. This doctrine, developed as case law from U.S. Supreme Court rulings, holds that the Federal government, when it withdraws public domain lands for the purpose of the creation of a Federal reservation, necessarily withdraws unappropriated water rights sufficient to meet the needs for which the reservation was created. The date of priority of these rights is the date of creation of the reservation. In the case of the Hanford Site, this date is 1943. It is the general rule that Federal reserved water rights cease to exist when the Federal reservation ceases to be used for the purposes for which it was created. The limited exception to the rule is reflected in the U.S. v. Powers, 305 U.S. 527 (1939), wherein the Court allowed that a purchaser of agricultural land on an Indian reservation may be entitled to a portion of Federal reserved water rights where the use of the property did not change.

The Federal government has not established its own water rights regulation. Instead, it uses the regulatory procedures outlined in the State water rights laws to document the extent of its rights. There has been no general adjudication in the State of Washington of the water rights in the Columbia River and, therefore, the reserved water right of the Hanford Site has not *been documented. The quantity of that right, however, would be equal to the maximum amounts used at Hanford during its operation, up to the amount of unappropriated water in the Columbia River as of 1943.*

In a report titled, Hanford Land Transfer (Washington Department of Ecology 1993), Ecology indicated that if water rights were attached to privately owned parcels of land acquired in fee by the Federal government for the creation of Hanford in 1943, those water rights may continue to be attached to these parcels of land. Ecology has indicated that it has not taken action to extinguish these rights, although under Washington law appropriative water rights are subject to be extinguished if unused for a period of five years.

Further complications exist regarding non-Federal water rights claims at the Hanford Site. The first is the issue of groundwater contamination at Hanford. The second is that the date for filing a water rights claim in the Hanford sub-basin, for both Columbia River water and groundwater, expired in 1992. No claims for water rights under state law appear to have been filed within the required time period (NPS 1994).

7.0 Conclusions

The area known as the Hanford Site in south central Washington has all of the components that favor successful irrigated farming. Environmentally, it has good soils, a mild climate and abundant high-quality water supplies. Economically, the Hanford Site benefits from the excellent transportation systems (roads, rail, and barge), extensive power systems, and the already well developed agricultural processing, supply and service infrastructure that supports the regions agriculture. Constraints to agricultural development of the Hanford Site are political and social.

In the event that irrigated agricultural land use is permitted, it is anticipated that only parts of the Hanford Site will likely be developed as irrigated agriculture in conjunction with wildlife and ecosystem reserves and the permanently restricted areas. A staged development scenario that integrates all uses may be the best process.

Potential land use and economic scenarios favor intensive large-scale agricultural development growing orchard and vegetable crops. Irrigation technologies would be limited to highly efficient methods such as center pivots and microirrigation. Precision agriculture techniques are likely to be more efficiently applied on large fields under limited ownership/management with resulting ecological benefits. These scenarios produce the fewest environmental problems with groundwater contamination and the flexibility to fit within eventual DOE operational strategies for groundwater management.

If portions of the Hanford Site are ever developed for irrigated agriculture, future development probably would focus on large-scale commercial enterprises that can afford to import clean water and employ high levels of water management to minimize deep drainage. Any suburban or small ranchette developments should be carefully examined in light of water safety concerns (real or imagined) and their generally poor levels of water management.

Numerous future advances in irrigation and resource conservation techniques are anticipated. Improved systems will be the norm in 50 years. Scientific irrigation scheduling and a network of supporting weather stations must be part of the total system for water and pest management of any future agricultural development on the Hanford Site. Because of the light soils and widely variable topography, new advances in microirrigation and self-propelled irrigation (i.e., linear move and center pivot systems) will probably have the most promise for future irrigation of new lands such as the Hanford Site.

A reasonable estimate of deep percolation in 50 years would be the current best achievable levels of the best technology: from 2% to 15% of the applied water not including water applied for frost protection or other non-irrigation uses. However, because of lack of uniformity in water distribution, soil types, topography, and imperfect management decisions, the deep percolation loss (recharge) is almost always larger than the required leaching fraction to prevent soil salination (about 2% of annual water delivery to the farm). Recharge from irrigation would probably range from 50 to 500 mm/yr compared to historical estimated natural recharge rates ranging from 0.1 to 10 mm/yr, even with the expected improved technologies and systems. Wine grapes would have the least recharge while field crops would potentially have the greatest deep percolation losses.

Extreme care must be exercised to avoid even the appearance that crops are irrigated with or otherwise exposed to toxic and radioactive substances, even at very low concentrations scientifically considered safe for humans. Agriculture is a large portion of the economy of Washington and a major source of exports. The delicate national and international trade balances would be easily upset by even unfounded rumors of contamination, resulting in huge economic consequences for agriculture throughout the Pacific Northwest.

The economic and political drivers can be anticipated to expand irrigated crop production in the Pacific Northwest. The most likely areas for future irrigated agriculture expansions are the undeveloped East High areas of the CBP and non-restricted areas within the Hanford Site. If environmental, water supply, and other concerns are met, it is probable based on current trends that both areas would be developed using private funding sources rather than public sources.

Obtaining adequate water rights for any irrigated development will be a major issue. Many of the salmon and steelhead fisheries in the Columbia River system are listed as endangered by the federal government. Thus, ecological consideration will have a significant impact on current and future development of regional water resources.

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Appendix

Summary of Current Agricultural Production in Grant, Adams, and Franklin Counties

Appendix

Summary of Current Agricultural Production in Grant, Adams, and Franklin Counties

Franklin County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	105,400	69.9	7,365,000	9
Wheat, Spring (bu)	15,600	59.6	929,000	9
Wheat, All (bu)	121,000	68.5	8,294,000	9
Barley (bu)	4,900	25.7	126,000	13
Corn for Grain (bu)	19,700	188.0	3,706,100	3
Corn for Silage (tons)	1,400	30.5	42,700	7
Potatoes (cwt)	42,500	620	26,360,000	1
Hay, Alfalfa (tons)	57,000	7.30	418,500	2
Hay, Other (tons)	2,400	5.80	14,000	18
Hay, All (tons)	59,400	7.30	432,500	2
Dry Beans (cwt)	2,700	24.80	67,000	3
Alfalfa Seed (cwt)	1,000	7.50	7,500	3
Kentucky Bluegrass Seed (cwt)	1,600	6.30	10,000	5
Other Grass Seeds (cwt)	900	6.90	6,200	2
Asparagus (cwt)	11,600	36.4	422,000	1
Carrots - Fresh (cwt)	300	460.0	138,000	3
Carrots - Proc (cwt)	2,200	27.7	61,000	1
Green Peas - Proc (cwt)	550	3.1	1,700	9
Onions, Storage (cwt)	3,900	515.0	2,008,000	2
Sweet Corn - Proc (cwt)	14,500	9.2	133,000	2
Source: Washington Agricultural Statistics Service				

Franklin County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	189	9,846	7
Apples	121	5,347	7
Apricots	7	105	6
Cherries, All	44	1,473	6
Grapes, All	40	2,328	3
Nectarines	9	94	5
Peaches	11	200	3
Pears	16	215	10
Plums & Prunes	5	(D)	-

Source: 1992 Census of Agriculture.
(D) = Not disclosed.

Grant County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	207,300	69.0	14,301,000	5
Wheat, Spring (bu)	39,600	75.8	3,000,000	1
Wheat, All (bu)	246,900	70.1	17,301,000	5
Barley (bu)	7,900	83.9	663,000	8
Corn for Grain (bu)	34,300	160.0	5,488,000	2
Corn for Silage (tons)	6,300	27.6	173,600	3
Potatoes (cwt)	40,500	590	23,895,000	2
Hay, Alfalfa (tons)	126,000	6.20	775,000	1
Hay, Other (tons)	8,900	4.10	36,500	7
Hay, All (tons)	134,900	6.00	811,500	1
Dry Beans (cwt)	12,900	23.20	299,000	1
Alfalfa Seed (cwt)	4,500	7.30	33,000	2
Peppermint (lbs)	6,000	100	600,000	3
Spearmint (lbs)	1,150	123	142,000	2
Asparagus (cwt)	1,900	36.8	70,000	3
Carrots - Proc (cwt)	1,400	32.9	46,000	2
Green Peas - Proc (cwt)	14,700	2.6	37,500	1
Onions, Storage (cwt)	4,000	515.0	2,060,000	1
Sweet Corn - Proc (cwt)	39,100	9.2	358,000	1

Source: Washington Agricultural Statistics Service.

Grant County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	292	29,337	2
Apples	243	24,154	3
Apricots	36	332	1
Cherries, All	87	1,945	4
Grapes, All	20	1,389	4
Nectarines	23	166	3
Peaches	26	154	5
Pears	52	1,034	4
Plums and Prunes	9	136	3
Source: 1992 Census of Agriculture.			

Adams County Crops - 1996

	Acres Harvested	Average Yield	Total Production	Rank in State
Wheat, Winter (bu)	286,000	58.7	16,787,000	4
Wheat, Spring (bu)	31,700	44.9	1,422,000	5
Wheat, All (bu)	317,700	57.3	18,209,000	4
Barley (bu)	6,900	58.0	2,552,000	3
Corn for Grain (bu)	5,900	157.0	926,400	6
Corn for Silage (tons)	1,600	30.0	48,000	6
Potatoes (cwt)	16,000	570	9,120,000	4
Hay, Alfalfa (tons)	19,500	6.50	126,500	4
Hay, Other (tons)	2,400	4.00	9,500	20
Hay, All (tons)	21,900	6.20	136,000	6
Dry Beans (cwt)	4,400	22.30	98,000	2
Kentucky Bluegrass Seed (cwt)	2,300	8.70	20,000	4
Peppermint (lbs)	7,000	104	730,000	2
Asparagus (cwt)	800	35.0	28,000	5
Onions, Storage (cwt)	1,000	500.0	500,000	4
Source: Washington Agricultural Statistics Service.				

Adams County Orchards - 1992

	Number of Farms	Total Acres	Rank in State
Land in Orchards	31	2,343	9
Apples	28	2,247	9
Cherries, All	4	(D)	-
Pears	5	(D)	-
Source: 1992 Census of Agriculture. (D) = Not disclosed.			

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