DEPARTMENT OF Agriculture Conservation & Forestry

2024

Maine Irrigation Guide

Information on Water-Source Development and Irrigation Practices

Updated By: Cumberland County Soil & Water Conservation District

Maine Department of
Agriculture, Conservation & Forestry

Acknowledgements

The 2024 Maine Irrigation Guide update was produced by the Cumberland County Soil and Water Conservation District through a contract funded by the Maine Department of Agriculture, Conservation and Forestry (DACF).

For the Cumberland County Soil and Water Conservation District, Katharine Kranich Wojcik provided graphic design, layout, mobile accessibility, editing, and sourcing; Heather Huntt updated the permitting section; Amren Frechette provided data and content updates; Christopher Baldwin, P.E. provided content updates and final review. Tom Gordon of DACF coordinated the project.

Thanks to reviewers for the 2024 Guide: Nancy McBrady, Craig Lapine, Tom Gordon, and Mark Hedrich (DACF); Brian Kavanah, Bill Sheehan, and Robert Mohlar (DEP Bureau of Water Quality); Robert Wood, Dawn Hallowell, and Mark Stebbins (DEP Bureau of Land Resources); Stacie Beyer and Arnie Arbo (DACF, Land Use Planning Commission); Sean Birkel and Rachel Schattman (University of Maine).

The original 2005 Maine Irrigation Guide was produced by the Central Aroostook Soil and Water Conservation District (CASWCD) with grant funding from the Maine Outdoor Heritage Fund. The Guide was based on 1994 and 1995 Best Management Practices Series on Water Management and Irrigation Management published by the Ontario Ministry of Agriculture, Food and Rural Affairs.

The 2005 Guide was drafted by David Brooks with Susan Webster as technical editor. Timothy Dalton (University of Maine Cooperative Extension) wrote the cost/benefit analysis section. Linda Alverson and Leigh Morrow (CASWCD) provided editing. John Harker (Maine Department of Agriculture, Food & Rural Resources) provided illustrations and guidance throughout the Guide's development.

Contents

1. Introduction

The intent of the Maine Irrigation Guide is to provide Maine growers with an irrigation information clearinghouse. This guide is designed to serve the members of the State's agricultural community who are currently irrigating or are considering irrigation. The Guide seeks to help growers accomplish these goals:

- To gain information about irrigation that will contribute to the economic viability of their crop
- To manage and use water sources for irrigation in an efficient, cost-effective, and environmentally responsible manner, keeping the environmental impact to a minimum

Before growers make an investment in an irrigation system or an upgrade, they need answers to the following basic questions:

- who to contact for information, services and/or equipment
- how much water is needed for their crop or field
- how to assess and develop sufficient and sustainable water sources
- how to keep on top of the regulations and permitting procedures that need to be followed when using or developing water sources
- how to select the appropriate irrigation system for their crop or field
- how to schedule irrigation and conserve water.

In 2024, the Maine Department of Agriculture, Conservation and Forestry, with the Cumberland County Soil & Water Conservation District, led an initiative to update the Irrigation Guide. This guide is a starting point for growers to establish irrigation systems and practices that will benefit their business as well as the public interest.

1.1 Why Irrigation is Needed

In Maine, irrigation is practiced primarily to provide crops with water to supplement deficiencies in precipitation. This provides two critically important economic benefits:

1) Protection from crop loss or damage due to weather-related factors, with drought and frost being the primary risks. Irrigation can reduce the risks associated with drought to the maximum extent practicable and economically feasible for each individual grower. Natural rainfall can be unpredictable; water must be available in sufficient quantity, of desired quality and at the optimum times during the growing cycle. Drought episodes in the last 8 years (2016-2017, 2020-2021) in Maine established drought as a higher risk than previously considered. Additionally, irrigation is useful for protection against frost, a major risk to many Maine crops.
2) Protection in the marketplace, to help the grower stay competitive by meeting the increasing demands by consumers and processors for consistency, quality, and quantity of the product. Repeated years of low crop yield or reduced quality due to drought could result in the loss of long-term contracts with major processors.

Supplemental irrigation has many benefits for crop growth, yield, and quality, including:

- **Crop Establishment.** Recently transplanted or seeded crops require water for seedbed activation, root establishment and/or germination, especially broccoli, carrots, rutabaga, tree fruits and nuts, berry crops, grapes, nursery stock and other field vegetables.
- **Plant Growth and Vigor.** Plants require water for all phases of growth, including cell division, cell elongation, photosynthesis, and transpiration during the growing season. It is the process of transpiration that provides a cooling effect to the crop as it grows.
- **Flower Setting and Fruit Development.** Adequate water supply enhances fruit and flower bud formation (feathering young trees), flowering, fruit set and fruit sizing.
- **Crop Quality.** The flavor, appearance and post-harvest attributes of certain fruits and vegetables can be improved with water-efficient irrigation. This is especially true for potatoes in Maine, where timing of irrigation will enhance development and postharvest storability. The major potato processors in Maine view favorably those growers with the ability to provide uniform quality. In some situations, some fruit and vegetable crops may not respond positively to irrigation water in terms of flavor or sugar development. (This may be cultivar- and soil type-specific.)

Other potentially high-value crops such as fruits, wild blueberries, sod, and nursery stock must be of top quality to win acceptance in the marketplace. Attaining quality requires timely management decisions—especially of crop production inputs.

1.2 Maine's Irrigation Challenges

Ty Finck, Blueberries on a Bush

Wild blueberry growers in Maine's Downeast region, after investing two years in growing a crop, can face a 30 to 100 percent reduction in crop yield if drought occurs in either crop year. In Aroostook County, growers know that the quality and appearance of their potatoes can be improved with water-efficient irrigation during short-term drought. Major potato processing plants in Maine have high standards for quality, and growers have learned that supplemental irrigation helps their product to achieve a consistently uniform quality with good processing characteristics. In addition, the timing of irrigating potato fields can be crucial to post-harvest storability. Without supplemental irrigation, potato growers' risk major losses of harvest due to drought. Other crops, such as strawberries and nursery crops, would be uneconomical to grow at all without an adequate source of water.

Nearly every crop grown in Maine can benefit from irrigation to improve the quality and quantity of the product. As one farmer explained, "irrigation is as important to maintaining farms as snowmaking is to maintain the ski industry." (from Growing Agriculture, App. 2, MAWMAC, 2003). For many agricultural producers, the economic risks associated with a potential lack of water are substantial, and a lack of access to water can spell the difference between a profitable harvest and financial loss. In 2020, over half of farmers surveyed in the Maine Drought and Agriculture Survey (Schattman, R. E., Goossen, C., and Calderwood, L. 2021. The 2020 Maine Drought and Agriculture Report. University of Maine, Orono. 1-30. DOI: 10.6084/m9.figshare.14474055) reported they did not have sufficient water to meet their farm's needs.

In surveys conducted by the Maine State Department of Agriculture, growers ranked irrigation as one of the most important technologies needed to keep them in business. Many growers interviewed believe the cost associated with installing an irrigation system is justified not only for increased quality and yield of crops, but to protect from partial or total crop failure. Other growers stated they might go out of business if they did not adopt irrigation. These facts are supported by Census of Agriculture data from the U.S. Department of Agriculture (USDA). Growers who irrigated some or all of their cropland represented the net gain of farms in the state. The farms that were not irrigating represented the net loss. The irrigating farms reportedly increased the market value of products sold per farm.

1.3 History of Irrigation in Maine

Irrigation of agricultural crops in Maine began in the 1950s and early 1960s with the wild blueberry industry in Washington County but did not begin in earnest until the early 1990s. In Aroostook and Penobscot counties, irrigation technology was introduced on potato crops in the early 1970s. Irrigation of potatoes and broccoli became more widespread in Aroostook County in the 1980s, and irrigation is presently used on other vegetable and fruit crops elsewhere in the State.

The growth in irrigation correlates to irrigation research documenting its benefits. Some of the more notable research includes: University of Maine studies on irrigation benefits to fruit trees (1970s); U.S. Army Corps of Engineers, St. John River Basin Cropland Irrigation and Conservation Research/Demonstration Program Feasibility Report (1980s); University of Maine irrigation experiments at the agriculture and forestry experiment stations in Presque Isle at Aroostook Farm, and in Jonesboro at Blueberry Hill Farm (late 1980s and early 1990s); research by private growers and processors, such as irrigation trials conducted by McCain Food LTD. in the St. John Watershed, in neighboring New Brunswick, Canada; and recent plant demand research by growers in the Downeast region. Ongoing research throughout Maine continues to demonstrate the benefits of irrigation, while refining data on plant water demand, irrigation methods, irrigation management and crop benefits.

1.4 Future of Irrigation in Maine

Statistics from the 2022 U.S. Census of Agriculture and the 2018 Irrigation and Water Management Survey (USDA National Agricultural Statistics Service) indicate that the practice of irrigation is on the rise in Maine. From 1992 to 2018, the number of acres irrigated rose from approximately 10,000 to 35,695 acres. To meet this demand, water sources, above and beyond rivers, streams, and lakes, will need to be developed to meet irrigation needs in an environmentally sustainable manner.

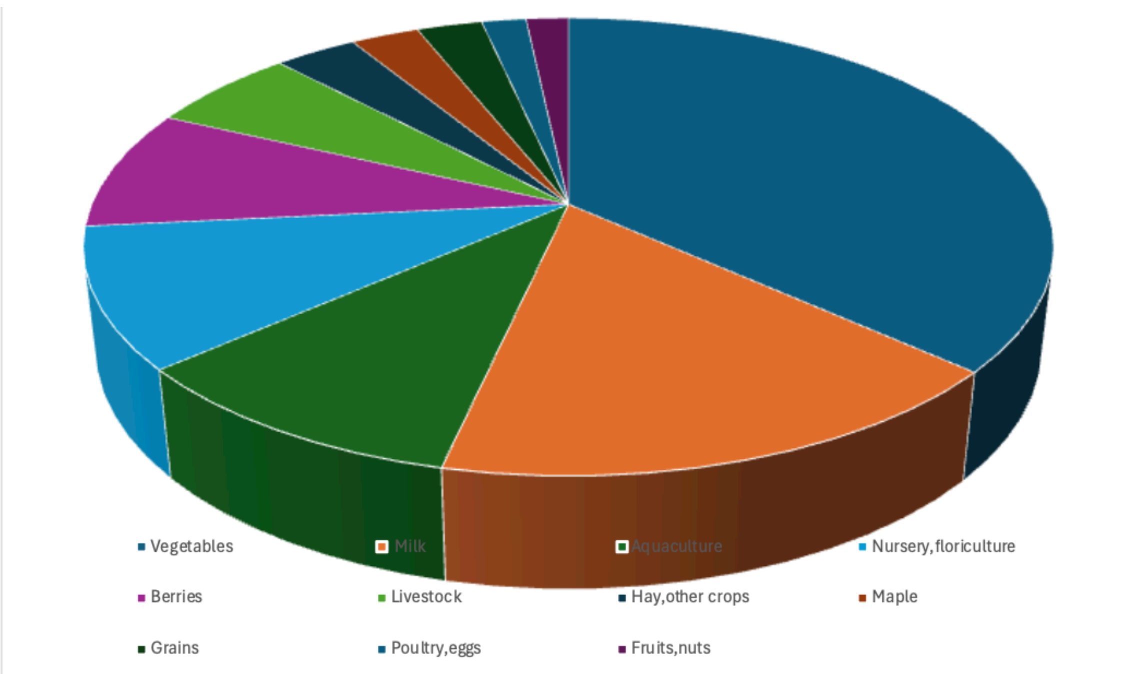
The 2020 rainfall deficit resulted in occasional record-low stream flows, with some farmers attempting to save their crops through excessive water withdrawals from streams and rivers. Reports from the Maine Climate Council's Science and Technical Subcommittee (Fernandez, I. et al. 2020. Scientific Assessment of Climate Change and Its Effects in Maine) suggest that Maine's climate will become increasingly variable with more frequent heat waves, intense downpours, and longer dry spells. As a result, the need for timely, available, and sustainable water is also increasing to help sustain this valuable sector of Maine's economy and rural way of life. Creating actionable climate change strategies is the goal of the Mills Administration's "Maine Won't Wait" Climate Action Plan. The Maine Department of Agriculture, Conservation & Forestry has developed the Farmer Drought Relief Program and Healthy Soils Program to provide technical and financial assistance for farms to improve farm productivity and resilience to climate change pressures and extreme weather events.

Cropland and Irrigated Acreage in Maine, 2022

	Total Farms	Total Acres	Average Acres	Irrigated Farms	Percent of Total Farms	Irrigated Acres	Average Acres	Percent of Total Acres
Vegetables	1,287	66,267	51.5	619	48%	15,364	24.8	23%
Berries	1,024	47,619	46.5	238	23%	13,555	57.0	28%
Orchards	662	2,847	4.3	87	13%	370	4.3	13%
Forage	2,446	165,521	67.7	53	2%	881	16.6	1%

USDA, 2022 Census of Agriculture, Table 35

Value of Agricultural Products Sold by Commodity in the $1000's



USDA, 2022 Census of Agriculture

1.5 The Decision to Irrigate

Factors to Consider Before Choosing to Irrigate

General Considerations	Details
WATER QUANTITY	• Sufficient volumes must be available on demand. • Design should accommodate peak crop needs (for frost protection, design should be able to accommodate several consecutive nights' use). • Strategy should be in place to recharge limited volumes of water.
WATER QUALITY	• Irrigation water must be free of contamination from pesticides (herbicides), heavy metals, organic solids, salts, nematode and other parasitic organisms. • Water must be of desirable temperature and pH.
REGULATIONS & LEGAL CONSIDERATIONS	• These must be complied with before drawing water to irrigate. • See Permitting in Section 6.
CAPITAL AND OPERATING COSTS	• Capital investment and operating costs can vary dramatically, depending on system type, power sources, usage pattern, crop, field location and maintenance.
LABOR & MANAGEMENT	• Irrigation systems demand differing degrees of input.
ENVIRONMENTAL IMPACT	• Irrigation should not jeopardize the water cycle of a fragile ecosystem, nor interfere with quantity or quality of flowing water for downstream users and aquatic systems.
SAFETY	• An irrigation pond poses a potential hazard, especially in areas where there is easy access. • Fencing should be provided, with warning signs posted in high-risk situations. • Certain irrigation systems may carry an inherently high risk while in use, because of high operating pressure or potentially dangerous electrical energy.

Source: Irrigation Management, Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995.

2. Irrigation Benefits for Specific Crops

Irrigation management practices listed in this section by type of crop may increase crop yield, quality, and, where technologically applicable, save water. The tables summarize some of the documented benefits of irrigation for specific crops, including recommendations for the most appropriate irrigation systems and critical irrigation periods for irrigated crops from fruit trees to nursery stock. Asterisks indicate the response benefits of irrigation to that crop. In addition, each table lists critical irrigation periods, commonly used irrigation systems and special considerations. The benefits of supplemental irrigation need to be determined for each irrigator depending on crops, desired quality and yield, management techniques, and potential water source.

2.1 Fruit Crops

Rooting Depth

- Varies with soil type, structure and rootstock.

Amount of Water Required:

Up to 10 gallons per mature bush per day during July and August:

- 1" every 14 days to maintain 50–100% available soil moisture
- 1" every week during July and August

Blueberry Harvest, Mario Mendez

General Notes on Irrigation for All Fruit

Irrigation improves plant establishment, nutrient use, and bearing area and plant health. It can also be used for frost control (sprinkler), fertigation and chemigation.

Overhead irrigation is recommended for frost protection, chemigation and evaporative cooling. Trickle irrigation is more suitable for fertigation than overhead sprinklers, and will cause fewer infections of scab, fire blight, brown rot, Botrytis fruit rot, etc.

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
APPLES ** Low to medium density on vigorous or semi-vigorous root systems *** High density systems (M26, M9 root stocks or equivalent)	Increased fruit size and yield More fruit bud initiation Less biennial bearing Reduces probability of bitter pit Trees are in better condition going into dormancy. Better growth and development of nursery stock Moderation of June drop	May–September (trickle) Bloom (through cell division stage) Fruit bud initiation (June) Fruit swell (August–September)	Traveling gun Trickle Fixed-volume gun	Standard trees usually require at least 63 gallons of water per week per tree to relieve stress during extended periods of drought. Large volume of water applied over short time periods are normally applied with a gun. More important on fully dwarfing rootstock. Use short wettings to avoid scab and fireblight spread. Uniform soil moisture may reduce bitter pit. Moderate or excessive summer pruning under drought conditions (with- out irrigation) may have a negative effect on crop volume and finish. Do not root prune on droughty soils unless irrigation is available—the added stress may also affect winter hardiness. Mulch to save water.
PEACHES & NECTARINES ***	Less thinning needed Fewer split pits Less canker Less winter injury Better hardiness Increased marketable yield	May–September (trickle) Pit hardening through fruit swell	Traveling gun Trickle Fixed-volume gun	Maintain 50% available soil water. Irrigation is critical if sod is established between rows. Longer tree life is expected from season-long irrigation. Use trickle or low risers to avoid spread of brown rot and bacterial spot. Maximum response to irrigation can be expected in the first five years after planting.
PEARS ***	Larger fruit and yields More fruit bud initiation Less biennial bearing Increased growth More critical in high density systems	May–September (trickle) Bloom Fruit bud initiation (July) Fruit swell (July–September)	Traveling gun Trickle Fixed-volume gun	Overhead irrigation may wash psylla residue off but may help spread fire-blight (less risk of fire-blight with trickle), scab and leaf spot disease. Avoid excessive growth with balanced nutrition. More critical in high density systems.

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
PLUMS ***	Larger fruit Reduced probability of heat spot and gummosis Reduced winter injury	May– September Pit hardening through fruit swell	Traveling gun Trickle Fixed-volume gun	Use short wetting to reduce spread of brown rot with overhead irrigation. Even soil moisture may reduce gummosis. Thin crop for maximum response.
CHERRIES **	Larger fruit Healthier trees Recovery after mechanical harvest	May -September Pit hardening through fruit swell Post-harvest	Traveling gun Trickle Fixed-volume gun	No irrigation after fruit color to avoid splitting and brown rot. Use short wetting to avoid lead spot infections with overhead. Irrigate soon after mechanical harvest.
APRICOTS ***	Larger fruit Less thinning required Less canker Reduced winter injury	May- September Pit hardening through fruit swell	Traveling gun Trickle Fixed-volume gun	Greater risk of spreading brown rot and bacterial spot with overhead than with trickle.
GRAPES *	Larger berry size Increased vine growth Increased yield in some years Increased sugar content during very dry years when leaf function may be limited.	Berry set through ripening period Avoid irrigation after early September to maintain sugar levels and reduce probability of late growth and winter injury.	Trickle	More response on clay soils. More response on coarse soils from larger vines. More economical for table and juice grapes. Avoid overhead irrigation, since it encourages disease spread, e.g., Downy mildew, Botrytis bunch rot, Phomopsis.
LOWBUSH BLUEBERRIES ***	Plant vigor and health Larger fruit Increased yields Increased root growth	Bloom (frost protection) Berry sizing through har- vest Post-mowing (renovation)	Hand-move port Solid-set	Avoid wet plants overnight.
HIGHBUSH BLUEBERRIES ****	Plant vigor and health Larger fruit Increased yields	May- September Bloom Berry sizing	Traveling gun Trickle Solid-set	Avoid wet plants overnight. Irrigation critical for establishment and growth. Requires 2" (50mm)/week during fruit development. Use a maximum (9L/day) per bush.

* *Seldom expect response benefits*
** *Some response benefits (30-60 percent of time)*
*** *Expect response benefits most years (75 percent of time)*
**** *Expect response benefits 9 years out of 10 (90 percent of time)*

Source: Irrigation Management, Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995

2.2 Vegetable Crops

SHALLOW-ROOTED VEGETABLES

Rooting depth of 1–2' (0.3-0.6 m) in most soils

Amount Of Water Required:

- Approx. 1" per week during vegetative growth
- Approx. 1.5–2.0" per week during critical periods

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
BEANS (Snap & Lima) **	Straighter, better-quality pods	Flowering, pod set	Hand-move port Fixed-volume gun Traveling gun Low-pressure boom	Improper irrigation can promote mold. Irrigate prior to flowering. Avoid watering in the evening. Allow foliage to dry before night to discourage dis- eases.
BEET (Red) ***	Better quality, better shaped roots Improved seed germination	Stand establishment Root enlargement	Hand-move port Fixed-volume gun Traveling gun Low-pressure boom	Uniform moisture required at all growth stages. Boron may be applied through irrigation if required.
COLE CROPS e.g., Broccoli, Brussels Sprouts, Cabbage, Cauliflower ***	Larger head size, quality Prevention of premature heading (buttoning) of cauliflower Prevents tip burn of cabbage Encourages uniform seed germination	Head formation and enlargement	Hand-move port Fixed volume gun Traveling gun Low-pressure boom	Broccoli seedbeds can be irrigated to stimulate germination if soil moisture is lacking. Excess irrigation can pro- mote tip burn in cabbage, head rot in cauliflower and broccoli. Boron may be applied through irrigation if required. Frequent irrigation is required for cauliflower grown in warm months to prevent buttoning.

Beets, Markus Spiske

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
CARROT ****	Seed germination Better quality, longer roots	Root enlarge- ment	Fixed-volume gun Traveling gun Low-pressure boom Sub-irrigation	High moisture requirement. Uniformity is important, as excess moisture causes cracking and short roots.
CELERY ****	Celery is very susceptible to drought at all stages. Drought causes black-heart (calcium-related breakdown of the center of the plant) and buttoning	Crop establishment to harvest	Hand-move port Traveling gun Low-pressure boom	Requires approximately 2″ (50mm) weekly. Celery shouldn't be grown without irrigation.
CUCUMBER Muskmelon Zucchini ***	Larger fruit Less crooked fruit Better quality	Flowering Fruit set Fruit sizing	Hand-move port Traveling gun Fixed-volume gun Trickle	Fertigation may be used with trickle to improve yield.
GARLIC On coarse-textured soils ****	Better quality, larger cloves	Vegetative growth, bulbing	Hand-move port Traveling gun Fixed-volume gun	Requires 1-2″ (25-50mm) weekly, especially in hot weather. Avoid watering in the evening to reduce disease development.
LETTUCE ****	Improved germination of direct-seeded lettuce	Head formation and sizing	Low-pressure boom Hand-move port	Irrigation important for seeded lettuce, especially in hot weather. Avoid watering in the evening. Allow foliage to dry before night to reduce disease development.
ONION ***	Larger bulbs More single centers	Bulbing and enlargement	Hand-move port Traveling gun Sub-irrigation	Requires 1-2″ (25-50mm) weekly Avoid watering in the evening; allow foliage to dry before night to reduce disease development.
PEPPER & EGGPLANT ***	Larger fruit, better quality, less sunscald and blossom-end-rot	Flowering Fruit set Fruit sizing	Hand-move port Traveling gun Fixed-volume gun Trickle	Fertigation may be used with trickle to improve yield.
POTATO ***	Better sizing, better processing quality, better appearance	Tuber formation and enlargement	Traveling gun Fixed-volume gun Low pressure boom Center pivot Lateral move	Irrigation may reduce soil temperature and improve tuber set in hot weather. Excess irrigation causes cracking, hollow-heart, and higher levels of tuber diseases.

*	*Seldom expect response benefits*
**	*Some response benefits (30-60 percent of time)*
***	*Expect response benefits most years (75 percent of time)*
****	*Expect response benefits 9 years out of 10 (90 percent of time)*

Source: Irrigation Management, Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995

MEDIUM-ROOTED VEGETABLES
Rooting Depth of 3.25′ (0.7 – 1.0 m) in most soils

Amount Of Water Required:
- Approx. 1″ every 10 days during vegetative growth
- Approx. 1.5 – 2″ every 10 days during critical periods

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
SWEET CORN **	Better pollination, fewer blank kernels, better tip-fill	Tasseling, pollination, ear filling	Traveling gun	Irrigation promotes good tip fill. Maximum 2-3 irrigations required in very dry years.
TOMATO (Fresh Market) ***	Larger fruit, better quality, less blossom-end-rot, less cracking	Flowering, fruit set, fruit sizing	Hand-move portable Fixed-volume gun Traveling gun Trickle	Fertigation may be used with trickle to improve yield.
TOMATO (Processing) **	Larger fruit, better quality, less blossom-end-rot, less cracking	Flowering, fruit set, fruit sizing	Traveling gun Low-pressure boom	Beneficial on coarse sandy soils; limited benefit on loamy soils.

* *Seldom expect response benefits*
** *Some response benefits (30-60 percent of time)*
*** *Expect response benefits most years (75 percent of time)*
**** *Expect response benefits 9 years out of 10 (90 percent of time)*

Source: Irrigation Management, Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995

Tomato Leaves After Watering, Zoe Schaffer

DEEP-ROOTED VEGETABLES
Rooting Depth is 3.25 – 6.5′ (1.0 – 2.0 m) in most soils

Amount Of Water Required:
- Approx. 2″ every 14 days

Crop	Benefit of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
ASPARAGUS *	Improved seed germination and seeding establishment	Stand establishment Usually no response on mature asparagus	Traveling gun Fixed-volume gun	Very deep-rooted crop; usually no irrigation response in mature asparagus Irrigation can be used for frost control in spring. Irrigation sometimes used after harvest is complete during periods of very dry growing conditions.
PUMPKIN (Melon, Winter Squash) **	Larger fruit, better shape	Flowering, fruit set, fruit sizing	Traveling gun Fixed-volume gun Hand-move portable	Deep-rooted crops show a minimal response to irrigation except in very dry season. Summer squash may show a more definite response pattern as it is a medium-rooted crop.

** Seldom expect response benefits*
*** Some response benefits (30-60 percent of time)*
**** Expect response benefits most years (75 percent of time)*
***** Expect response benefits 9 years out of 10 (90 percent of time)*

Source: Irrigation Management, Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995

Pumpkin on Vine, Jonathan Kemper

2.3. Nursery Stock

Field Grown Trees, Christin Hume

FIELD GROWN NURSERY STOCK

Type of Stock	Benefits of Irrigation	Critical Irrigation Periods	Amount of Water	Commonly Used Systems	Considerations
SEED BEDS	Improves seeding germination	During germination	0.5 – 1" per week; maintain near field capacity	Hand-move portable Semi-permanent Solid-set	Keep soil moist during seeding germination.
LINER BEDS & ROWS (7" ROOTING DEPTH)	Improves transplant establishment Increases plant size	During and after transplanting	0.5 – 1" per week; maintain near field capacity	Handmove portable Traveling gun Semi-permanent Solid-set	Irrigate budding under stock prior to budding. Irrigate post planting. Irrigate when soils are at 50-70% of field capacity.
CALIPER TREES	Maintains viability Ensures winter viability Increased insect and disease resistance Increases market-ability		0.5 – 1" per week; maintain near field capacity	Hand-move portable Traveling gun Trickle	Irrigate post planting.

CONTAINER GROWN NURSERY STOCK

Crop	Benefits of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
CONTAINER-GROWN SEEDLING	Improves seeding germination Maintains uniform and vigorous growth	Daily during growing season	Hand-move port Semi-permanent Solid-set Low-pressure boom Mist lines Hand watering	Good for a greenhouse or an enclosed production area. Requires careful judgment and experience. Ensure even coverage of water: each cavity must receive the same amount of water. Water must have low salts and be free of disease organisms. Plants vary in response to watering. Covering cavity with grit conserves moisture. Amount depends on medium, temperature, and plant. 0.6 gallon watering per container four times weekly. Over-watering should be avoided because of potential for damping off.
NEWLY POTTED & ESTABLISHED CONTAINER STOCK	Helps nutrient uptake from controlled-release fertilizers Evaporative cooling of plants Maintains health of establishment stock	Following transplanting in the fall prior to covering with poly houses Can be used to leach when total salt readings exceed 3.5 Daily during growing sea-son	Trickle Solid-set Solid-set pulsed delivery system	Good for container of 1–5 gal. Inefficient – only 15-55% of water reaches the medium. To improve efficiency: Offsetting spacing of container is more efficient than square spacing. Group plants according to their water requirements, pot size, rate of growth, age. Shift plants into larger containers before plants have reached their maximum canopy size, instead of spacing containers. Use controlled-release fertilizers. Using an automated system, water is applied in regularly timed intervals, e.g., a cycle may consist of 4 intervals on for 15 minutes, and then off for 30 minutes – this allows water to percolate through the pot (uses 30% less water).
CONTAINER-GROWN NURSERY STOCK	Maintains rapid and vigorous growth Reduces or eliminates transplant shock	Daily during growing season	Solid-set Trickle	Used for containers larger than 5 gal. Uses 75% less water than overhead irrigation system. Requires an automated system capable of delivering 0.2–0.4 gal. per 2-gal. container per day. Still in experimental stage.
PROPAGATION OF NURSERY STOCK	Prevents cuttings from dehydrating	Until cuttings are rooted	Solid-set Intermittent mist lines	Keep water on the leaves to maintain evaporative cooling. Requires a time clock or electronic leaf, interval adjusted to crop requirements.

2.4 Sod

Crop	Benefits of Irrigation	Critical Irrigation Periods	Commonly Used Systems	Considerations
SOD	Brings turf off dormancy to allow sod to be harvested Moistens root zone prior to harvest	Mid-summer	Center pivot Lateral move Traveling gun	Rooting depth: 4–8” Excess irrigation during evening or night can promote disease.

Sod Installation, Getty Images

3. Water Use Management Planning

Planning for water needs is critical to reduce the risk associated with droughts and frosts, and to improve the quality and quantity of crops. Planning should consider the crop's needs and response along with the environmental concerns. In addition, knowing the volume and flow rate characteristics of water resources help to match the proper water resource to total water needs.

The first step in evaluating the cost-benefit of irrigation is the development of a Water Use Management Plan. The Plan is based on two factors: plant water demand and available water supply. After determining how much water specific crops demand, growers can develop a water source and select an irrigation system that is the appropriate size for their business. Armed with this information, growers can compare capital and labor costs to an estimate of economic benefit (either in increased income or protection from loss).

For answers to concerns regarding irrigation management and assistance with the Water Use Management Plan, growers should contact the U.S. Department of Agriculture- Natural Resources Conservation Service (USDA-NRCS), and/or consultants and irrigation equipment suppliers (refer to appendices for contact information).

Additional resources are available through USDA and NRC programs:

- www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives/maine/environmental-quality-incentives
- www.nrcs.usda.gov/programs-initiatives/ama-agricultural-management-assistance/maine/agricultural-management

Pond in Front of Barn, Sikes Photos

FACTORS TO CONSIDER WHEN DEVELOPING A WATER USE MANAGEMENT PLAN	
Concern	Questions for the Grower
QUANTITY: Sources (see Section 4 for more information)	Are aquatic systems being put at risk? • Large rivers and lakes within reach can supply large amounts of water, while small watercourses and wetlands have limited supplies. • Construction of impoundments, ponds and stream pumps to facilitate water-taking can disturb watercourses, and ultimately disrupt the aquatic environment. • In some situations, a minimum suction screen size will pre- vent destruction of small fish. • Groundwater supplies may not be sustainable. • Cumulative effect of several water-taking projects on a single groundwater or surface water source must be evaluated. • Excessive taking from groundwater may result in contaminants traveling from upper groundwater to deeper aquifers. • Stands of deeply rooted woody perennials such as apple orchards or natural woodlots can suffer from drastic changes in water table depth. • Large groundwater- and surface water-takings can lower levels in wetlands, small streams, and in nearby wells particularly during periods of drought.
QUANTITY: Equipment (see Section 4 for further information)	Is equipment being maintained and used properly? • Pressure gauges become unreliable if used for purposes other than irrigation, e.g., spreading liquid manure. • Check nozzle wear, sprinkler alignment, pump wear, etc. • Is the best available technology being used to conserve water? (timers, moisture sensors)
QUANTITY: Timing (see Section 5 for further information)	Is water extraction being scheduled to ensure adequate stream flow remains and regulatory requirements are being met? • Time water applications for desired crop response. • Avoid impact on aquatic ecosystems and hydrology.
QUALITY	Is quality of irrigation runoff acceptable for downstream users and reuse? (See Permitting Requirements) • Will water from deep groundwater sources, which can contain impurities, have harmful surface water impacts due to uncontrolled movement? • Analytical testing for PFAS performed?

3.1. Elements of a Water Use Management Plan

The Water Use Management Plan combines site-specific and crop-specific conditions with the individual grower's needs. Maine possesses significant water resources in association with its farmlands. The challenge for Maine growers is to manage the water resource to make sure it is available when needed. This means understanding:

- how much water is needed for the crops produced
- what sustainable water resources are available
- what the best irrigation system is for the crop and water source

After decisions are made regarding the water budget, water resources, and irrigation equipment, irrigation scheduling is critical so water can be applied:

- where needed
- when needed for maximum impact
- in a way to conserve water

NRCS outlines the Water Management process and code at the following link:
https://efotg.sc.egov.usda.gov/#/state/ME/documents/section=4&folder=-139

The Water Use Management Plan is an important overall planning tool for every grower. In addition, the completed plan may also meet the needs of a permitting agency for water supply alternatives analysis. The better the understanding of water supply and demand, the better the cost benefit analysis potential for success in developing effective irrigation systems.

3.2 Uses for Irrigation Water

A grower needs to know what the goal is for using the water: is it for frost protection, increasing plant germination, stand, yield and quality, or for drought protection only?

Traditionally, crop irrigation has been used to augment the natural rainfall in Maine to prevent crop loss due to drought. Increasingly, growers and risk management agencies are promoting irrigation to reduce drought risk and reduce the need for expensive insurance premiums for that risk. Drought is the most important risk factor in agriculture, followed by too much rain as the second most important risk factor, and frost as the third (USDA, Climate Indicators for Agriculture, 2020 https://www.usda.gov/sites/default/files/documents/climate_indicators_for_agriculture.pdf)

Supplying water for crop use is not the only useful function of an irrigation system. It can also be used to apply crop protection materials to high-value crops. Frosts, sandblasting and excessive heat can be controlled in some situations. Also, in selected crops, productivity can be increased, and quality improved by applying crop nutrients with irrigation water through "fertigation". Fertigation is normally done using established drip (also known as micro-irrigation or trickle) systems.

Due to the increase in research on water use done by universities and private labs, growers are beginning to utilize targeted supplemental irrigation to:

- improve germination,
- improve crop quality and yield,
- minimize frost damage,
- provide heat protection,
- protect from sanding,
- harvest (cranberries and rice),
- provide insect control, and
- protect from winter desiccation and cold injury.

In Maine, these practices are becoming more important as competition from the western United States and international markets require Maine growers to have top quality crops and efficient operations.

ELEMENTS OF A WATER USE MANAGEMENT PLAN

- Cost analyses including the cost of water supply, equipment, and operation and maintenance of the system.
- Feasibility of irrigation regarding the availability of water, crops and varieties irrigated, soil management, environmental impact, local, state, and federal permitting, and noise.
- Water source evaluation show location, capacity, and drainage area of existing or proposed water sources and state reasons others were eliminated.
- Water management practices to ensure that the amount of water used for crop irrigation will be kept to a minimum.
- Irrigation scheduling method soil type.
- Rotation.
- Crops to irrigate irrigated acres.
- Consumptive use (in inches per day) maximum intake rate (in inches per hour) maximum application rate (in inches) amount of water required (in acre-feet) planned pumping rate.
- Maximum anticipated seasonal water needs (in acre-feet).
- Type of application equipment including overall system efficiencies.
- A soils map with the irrigated acres delineated.
- A topographic map showing irrigated acres and location of source.

3.3 Irrigation Water Budget

Once the decision is made to irrigate, growers need to establish the amount of water needed for their various crops. If there are any animals or other water needs, those factors also must be figured in to the amount of water to be used.

Many sources of information exist regarding the needs of crops for irrigation water. The local Cooperative Extension specialist or university crop research faculty can also be of assistance. In Maine, some crops, such as wild blueberries, cranberries, potatoes, and strawberries, have ongoing research programs to establish when and how much water is necessary. A rule of thumb is that a crop needs about 1 inch of water per week to maintain adequate soil moisture to grow. This total water need can be met by precipitation and supplemented by irrigation when necessary. For specialized crops, such as cranberries, sizable amounts of water are needed for special practices such as flooding for harvest, winter protection, etc. These water needs all must be figured into the irrigation budget.

For standard crop irrigation in the summer, growers will need to determine an average weekly rainfall amount for the area from weather records, and then figure the difference between the rainfall and crop need to determine the amount to supplement with irrigation. These records can be found through data from the Maine Climate Office: www.mco.umaine.edu
https://mco.umaine.edu/ageye/?site_id=me001.

To determine a final figure for the total irrigation water budget, for each field unit or pumping source being considered, growers need to know . . .

- How much water a crop needs on a weekly and yearly basis.
- How much water is needed by other farm uses on a weekly or yearly basis.
- Soil type and water holding capacities (see information in Section 5, on water intake rate).
- Acreage of land to be irrigated.
- Type of system to be used to apply the water and the system's level of efficiency.

Spray Irrigation, Philip Junior

3.4 Types of Water Resources

The following table lists the potential water resources and their respective planning considerations, permitting issues, and potential costs and benefits. Additional details on specific sources are included later in this section.

Planning Considerations		Permitting Issues	Potential Cost and Benefit
Natural Flowing Water Source: (Direct withdrawal)	During periods of demand, make sure water flows or levels are within requirements of DEP Regulation Ch. 587Use existing flow gauge data when available.	Certain irrigation projects may require permitting for groundwork by DEP under the Natural Resource Protection Act (NRPA). Additional information on the NRPA is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/index.html. DEP Regulation Chapter 587 specifies the water levels and flows that must exist, and be maintained, for water bodies to be used as a source of irrigation. Permits needed in LUPC service area.	Lowest cost solution
Natural Storage: Existing ponds and lakes	Make sure water withdrawals do not draw down ponds or lakes below a certain level. Consider needs of nesting waterfowl and fur-bearing mammals. Take prevention measures for noise abatement.	Regulatory requirements the same for natural flowing water (above).	Low cost, similar to direct withdrawals
Man-made Storage Dugout Ponds	Locate off stream and in marginal upland/low value wetlands to minimize impact to wetlands.	In organized townships a permit may be required from DEP depending on a variety of factors. More information can be found here: https://www.maine.gov/dep/land/nrpa/ A permit will be needed regardless of wetland impact in LUPC service area.	Moderate to high cost, but most protective of crop from risk management perspective since amount of water needed can be engineered into the size of the pond from the start.
Man-made Storages: Bypass Ponds	Like dugout ponds but utilizes bypass channel from stream for filling. Locate in suitable upland or low value wetland.	Permits needed for this type of work in organized and unorganized towns.	Similar to dugout ponds
Man-made Storages: Dams in continuously flowing streams or springs	Allow at least ABF or inflow to continuously bypass dams to assure that fisheries and aquatic habitat are maintained downstream.	Permits will be needed but some projects may qualify for a general permit in unorganized townships.	Moderate to high cost and time consuming, due to environmental regulation at both state and federal level. Federal level has mitigation requirements as well.
Ground-water: Springs	Determine flow rates during period of expected demand.	No permitting needed in organized townships if greater than 75' from a stream. Permits needed in LUPC service area.	Low cost, similar to direct withdrawals
Ground-water: Wells	Determine sustainable yield of well needed for irrigation while avoiding off-site groundwater impacts.	No permitting needed in organized townships if greater than 75' from a stream. Permits needed in LUPC service area.	Moderate cost, usually requires specialized consultants

The amount of land to be used for irrigating must be established at this point so that total water use per year can be determined.

The type of application system to be used and its level of efficiency needs to be determined and can be very variable, depending on the crop, type of land, topography, etc. Irrigation technology is improving, responding to growers' demands for more efficient systems. Newer systems meet crop needs with more efficient distribution of water. Gentler application methods help maintain soil structure, avoiding compaction problems. If an irrigation system is already in place, then an equipment dealer can help with an analysis of the efficiency of the operation. If a new system is being purchased, growers should ask for help with the design features for their site, and calculated efficiencies. Information on irrigation systems is included in Section 4.

3.5 Water Source Consideration

The water source selected will depend on local streams, ponds, and lakes, or what can be constructed, including wells, ponds, and impoundments. Part of the planning process is to evaluate the various potential sources based on location, ability to be permitted (if necessary), and cost. A list of potential water resources and methods of evaluation is found in Section 4.

3.6. Natural Flowing Water Sources

Natural flowing water sources are streams, flowages, brooks, and rivers. Except for flowing rivers with high discharge rates and low water demands, natural flowing water is not a reliable irrigation water resource because growers generally need water the most when flows are at their lowest (August to September). This often results in inadequate supply and can create direct conflicts with fisheries and recreational use and water quality. However, flowing surface waters can be used to refill storages during times of high flow, such as after periods of heavy rain.

Natural Flowing Water—Limitations

Federal Regulations:

- As of June 2004, a permit is not required for water withdrawals from flowing waters, unless there are other impacts that trigger a permit (for example, disturbing soil adjacent to a protected resource such as wetlands).

State Regulations:

- MDEP: As of August 2007, water withdrawal from waters of the state is subject to the requirements of DEP regulation Chapter 587: In-Stream Flows and Lake and Pond Water Levels. https://www.maine.gov/dep/water/swup/index.html
- Water may be withdrawn from surface waters for agricultural irrigation under the following conditions:
    - When water levels or flows are higher than those specified in the rule for a water body type or class, irrigation water may be withdrawn without approval. This is self-implementing based on the water levels and flows and no permit is required. (During times of moderate to exceptional drought, water flows in streams and

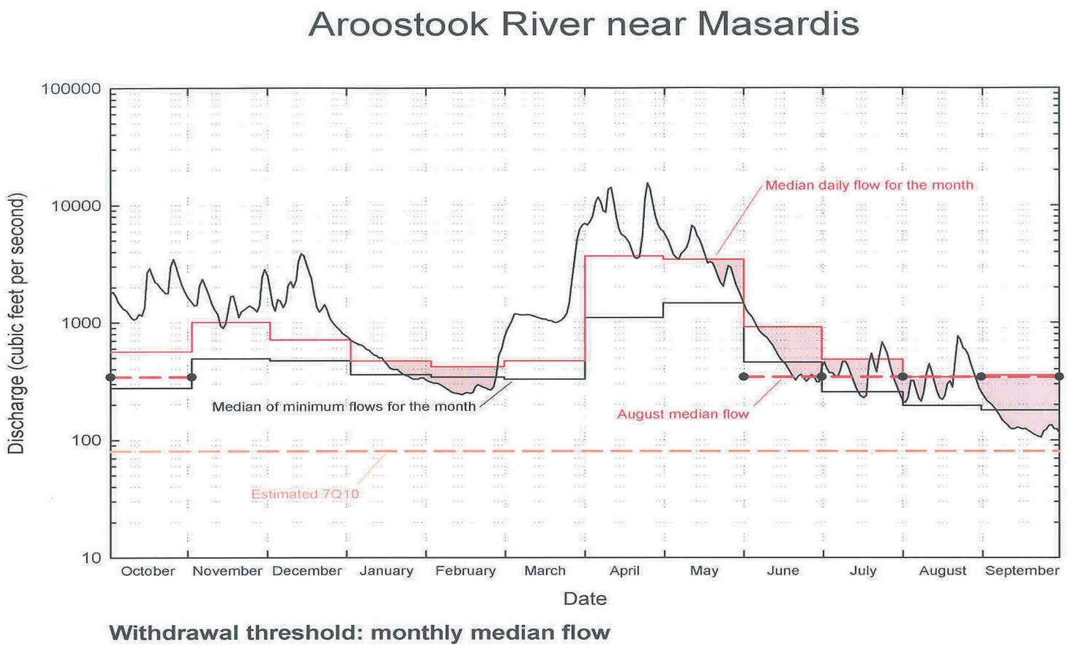
rivers will likely be lower than the required levels and may not be used for irrigation without site specific DEP approval as noted below.)

  - When the water levels or flows are lower than those specified in the rule for a water body type or class, irrigation water may only be withdrawn with site-specific written DEP approval. Site-specific approvals are based on information provided by the applicant and collected by the DEP. The process requires a 30-day public comment period and consultation with other natural resource agencies such as Department of Inland Fisheries and Wildlife and Department of Agriculture, Conservation and Forestry. To issue a site-specific approval, the DEP must be able to establish site specific water levels or flows that would enable a finding that all water quality standards will be attained.
  - In addition, for rivers or streams, DEP interprets Maine Law at 38 M.R.S., Sec. 470-B to allow withdrawal of 20,000 gallons per day, or withdrawal of one percent of the estimated low flow volume that occurs for 7 days in 10 years based on historical flows, and for lakes and ponds withdrawal of volumes in gallons per week based on acreage of the waterbody, as specified in the law.
- Certain irrigation projects, depending on their design and implementation, may require permitting for groundwork by DEP under the Natural Resource Protection Act (NRPA). Additional information on the NRPA is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/index.html.
- LUPC: A permit is currently required to use any significant volume of water from a flowing water source.

Natural Flowing Water—Flow Limits

Chapter 587 establishes river and stream flows and lake and pond water levels to protect natural aquatic life and other designated uses in Maine's waters. Instream flow requirements for Class AA, A, B, and C waters are based on natural flows that occur in Maine waters, and the uses and characteristics assigned by the water quality classification program (38 M.R.S.A. Sections 464, 465) with attention given to protecting the outstanding natural resources associated with Class AA waters. Flow is managed to provide natural variation of flow described by seasonal aquatic base flows, or other seasonally variable flows, shown to protect aquatic life resources and water quality standards.

Instream flows and water levels may be established by 3 methods: (1) standard allowable alteration, (2) by a site-specific flow designation developed through an Alternative Water Flow or Alternative Water Level, or (3) as part of a new or existing regulatory permit.



Natural Flowing Water—Flow Monitoring

To properly assess a flowing surface water source, existing flow data, calculations or measurement of flow rate should be made, especially for the low flow periods. It is important to collect this background data as part of the planning process prior to constructing an irrigation system.

Some major rivers and streams have flow monitoring gauges such as those operated by USGS. Permit flow limits are sometimes based on the flow rate at the gauge. However, flow limits sometimes need to be known at the point of withdrawal to assure compliance with permits. The water height at which the flow limit occurs is usually determined by developing a stage-discharge (water height to flow rate) relationship at the compliance point. Once the stage-discharge relationship is developed at the site, a surveyed staff gauge (usually marked in feet) is placed in the stream and a mark placed at the level where the flow limit(s) is reached.

Flow measurements can be calculated by one of the following three methods:

- velocity-area method, in the natural channel or a culvert,
- volumetrically, measuring the time required to fill a bucket from a raised culvert,
- using hydraulic structures or devices (like weirs, flumes, etc.

Additional information on flow measurement methods can be obtained from the USGS web site: How Streamflow is Measured | U.S. Geological Survey (usgs.gov).

Natural Flowing Water—Construction

Water withdrawals from flowing surface waters usually require the construction of roads and a flat surface for the pump. The suction lift from the lowest water surface should be as low as practical. The maximum suction for the pump should match the site; generally, 10 to 15 feet is acceptable.

Because of the proximity to surface water, Spill Prevention, Control and Counter Measure (SPCC) Plans should be developed, and necessary containment structures and cleanup materials kept on site for liquid fuel sources. MDEP or consultants should be contacted for help in developing SPCC Plans.

Proper erosion control practices such as sediment barriers, hay bales, and soil stabilization by seeding and mulching are required. Contact MDEP, NRCS, local SWCD or consultants for help with erosion control practices.

3.7 Natural Storages

Natural storages include lakes, ponds, and flowages. In general, if the natural storage is significantly larger than the area to be irrigated, and there are only limited water demands on the resource, natural storages can be a reliable resource for irrigation water. However, any potential environmental impact can create conflict with fisheries, recreational use, and property owner.

Federal Regulations:

- A permit is not required for water withdrawals from natural storages, unless there are other impacts that trigger a permit (for example, disturbance in or adjacent to a protected resource such as wetland or great pond).

State Regulations:

- MDEP: Water withdrawal from waters of the state is subject to the requirements of DEP regulation Chapter 587: In-Stream Flows and Lake and Pond Water Levels as noted in Natural Flowing Water−Limitations section above: https://www.maine.gov/dep/water/swup/index.html
- Certain irrigation projects, depending on their design and implementation, may require permitting for groundwork by DEP under the Natural Resource Protection Act (NRPA). Additional information on the NRPA is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/index.html.

LUPC: A permit is required to use any significant volume of water from a natural storage.

Natural Storages—Water Level Limits

In accordance with Chapter 587, water level requirements for Class GPA waters take into account natural variation of water levels that occur in Maine lakes and ponds, and the uses and characteristics assigned by the water quality classification program (38 M.R.S.A. Sections 464, 465-A). Water level is managed to provide variation that takes into account expected seasonal levels shown to protect aquatic resources and other water quality standards of Class GPA and downstream waters.

Agreement of the high-water mark elevation is often done by consensus between the permittee and the MDEP or LUPC staff during field inspections. The normal fluctuation of natural storage levels varies depending on size, type of storage, and geology. Therefore, as part of the process of

evaluating water resources and developing a plan for irrigation, it is important for growers to obtain the background measurement of seasonal level changes, as well as information on waterfowl nesting and fur-bearing mammal use. These background data are useful for growers to have when negotiating permit level limits and when evaluating the effects of pumping on the water resource.
www.usgs.gov/special-topics/water-science-school/science/how-streamflow-measured

Natural Storages—Storage Assessment
To properly assess a storage source, estimates of recharge rate, pond volume, and storage fluctuation needs to be collected.

Natural Storages—Recharge
Recharge rates are technically difficult to determine. Unless the pond is in coarse sand and gravel deposits that provide good recharge, it is sometimes best to assume that no recharge occurs.

Natural Storages—Volume
Surveys of pond area and depth are helpful to determine the volume of water available over the range of the estimated stage changes at 0.5, 1.0 and 2 feet. Depending on the level of accuracy needed, these measurements can be made by locating points with a hand-held GPS or by survey. Depths are then measured from a reference level (surface of the water, or from ice level in winter) to the pond bottom. The X, Y, and Z coordinates can then be plotted and elevation or depth contour lines drawn. The area of each contour line is then calculated (by counting grid blocks, planimeter or other methods). The average area of two successive contour elevations is calculated and multiplied by the difference in elevation to calculate approximate volume available in storage (see the following example).

100-foot Contour Area 2.0 acres
99-foot Contour Area 1.8 acres

Average Area Between Elevation 100 and 99 feet $= \frac{2.0 + 1.8}{2} = \frac{3.8}{2} =$ 1.9 acres

Estimated Volume Between Elevation 100 and 99 feet = 1.9 acres x (100-99 feet) = 1.9 acre-feet

The accuracy of volume estimates is a function of the number and spacing of the survey measurements and the increments of the contouring. The more accurate the contour intervals, the better the estimate and understanding of available water in storage. Computer software such as AutoCAD or similar applications are commonly employed by engineers to perform these volume calculations.

Natural Storages—Storage Fluctuation

Water levels and storage volume decline during dry periods, due to evaporation and reductions in recharge from groundwater. When possible, these natural declines in water level should be measured and documented over several years along with a variety of weather conditions for use in planning and negotiating level limits.

Natural Storages—Construction

Water withdrawals usually require the construction of roads and a flat surface for the pump. The suction lift from the lowest water surface should be as low as practical. The maximum suction for the pump should match the site; generally, 10 to 15 feet is acceptable.

Because of the proximity to surface water, Spill Prevention, Control and Counter Measure (SPCC) Plans should be developed, and necessary containment structures and cleanup materials kept onsite for liquid fuel sources. MDEP or consultants should be contacted for help in developing SPCC Plans.

Proper erosion control practices, such as siltation fencing, hay bales, and soil stabilization by seeding and mulching are required. Contact MDEP, NRCS, local SWCD or consultants for help with erosion control practices.

Certain irrigation projects, depending on their design and implementation, may require permitting for groundwork by DEP under the Natural Resource Protection Act (NRPA).

Additional information on the NRPA is available on the DEP's website here:
https://www.maine.gov/dep/land/nrpa/index.html.

3.8 Man-made Storage

Man-made ponds for irrigation can be constructed by excavation or impoundment (damming) or combination, varying in size from 0.5 to 50 acres.

Man-made Storages—Dug-out Ponds

In organized townships a permit may be required from DEP depending on a variety of factors. More information can be found here: https://www.maine.gov/dep/land/nrpa/. LUPC permits will be needed in unorganized towns. The U.S. Army Corps of Engineers may require a permit and significant wetland mitigation. Ponds can also be built in upland areas, but recharge can be limited by soil type and topographic location and will therefore require more storage capacity and/or an alternate recharge source. While permitting may not be required, upland ponds can also be more expensive to construct and operate than ponds in low-lying areas.

Man-made Storages—Impoundments
Impoundments are generally defined as small dams (less than 35 feet high) built across small streams or springs. These are usually well designed for water storage because they capture runoff and groundwater recharge. Obtaining permits to dam significant water courses can be costly if possible. Impounding of spring areas, although still complicated, will usually have less impact on wetlands and aquatic habitat and require less permitting. Permits will be required from MDEP and LUPC. Some impoundments may qualify for an Agricultural Irrigation Pond General Permit, www.maine.gov/dep/land/nrpa/agri_pond.pdf. An individual Army Corps permit may be required and mitigation of impacts may have to be addressed.

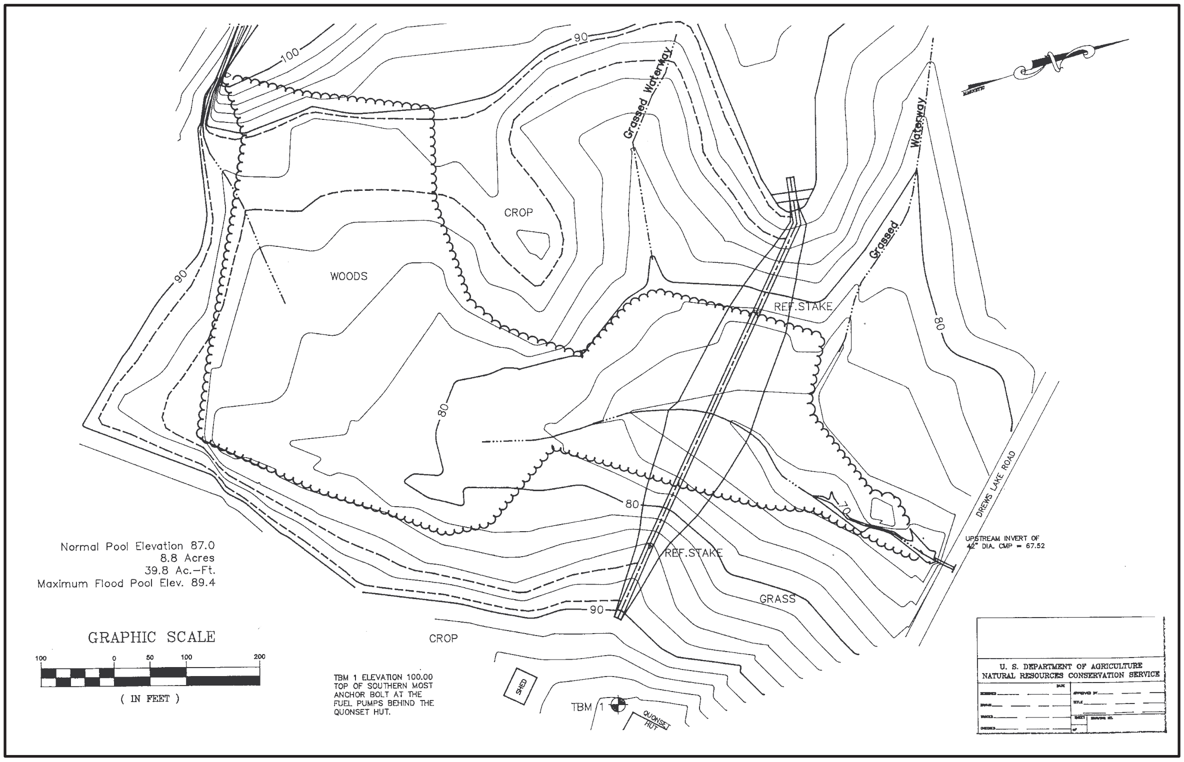
The recharge of any man-made storage can still be limited in mid- to late summer as discussed previously. Permitting is primarily affected by impacts on wetlands, and fish and wildlife habitat. Help from local SWCD, NRCS, MDEP, LUPC, and consultants should be sought early in the planning process. Additional information on permitting follows in Section 6.

Man-made Storages—Limitations
Federal and state regulations: A permit is generally required for construction of man-made storage ponds or impoundments in or adjacent to a stream or wetland area. LUPC permits may be needed in unorganized areas. There are certain state exemptions for agricultural ponds in wetlands and a streamlined process for construction in certain types of streams. However, if significant wildlife habitat is affected, permits may be difficult to obtain.

The federal permitting process has historically been lengthy, due to wetlands rules and the need to mitigate wetland impacts. The key to minimizing cost and time delays in permitting is to get help from SWCD, NRCS, and a consultant early in the review of potential sites, and to involve permitting agencies once a potential site(s) is selected.

The design of a dam must be done by a Professional Engineer to standards set by the State of Maine. The NRCS also has its own standards for dam design. If the dam is built in a stream, as defined by MDEP, it may also be necessary to maintain the flow downstream (see discussion of flow limits), either the aquatic baseflow or inflow to the pond, whichever is less. The collection of background flow data on stream or spring flow is critical to negotiating reasonable flow release limits. Other considerations will be potential impacts on adjacent property due to flooding, noise, and hazards. An excellent source of pond information is the NRCS Agriculture Handbook Number 590, Ponds−Planning, Design, Construction.

Also available online at: https://www.nrcs.usda.gov/sites/default/files/2023-05/NRCS%20Agricultural%20Handbook%20590.pdf



Example of dam plan

Man-made Storage Assessment

To assess a man-made storage source, the minimum information requirements are:

- delineation and identification of wetland areas
- information on soil stratigraphy (from borings, test pits, etc.)
- estimates of pond recharge or refilling rates
- locations for disposal of excavated soils
- determination of drainage area

If the natural recharge of the pond is low and the water demand high, the cost of constructing a storage pond that is large enough can be prohibitive. In that case, recharge sources should be evaluated. Once a sufficient recharge rate or alternate refilling source is identified, a smaller pond can be designed to meet demand. The analysis of storage volume needs to consider not only the total seasonal volume, but the short-term change in storage that occurs between irrigation events: the irrigation flow rate, time period, recharge flow rate, recharge time period, and seepage.

Formulas for Calculating Irrigation Volume and Pond Recharge Volume

Irrigation Rate 500 gallons per minute (gpm)
Irrigation Time 12 hours per day, 4 days per event
Irrigation Events per season 6 (7-day intervals)

Irrigation Water Use

Irrigation Volume = Irrigation Rate x Irrigation Time x Conversion Factors (gallons per event) = 500 gpm x 60 minutes/hr x 12 hrs/day x 4 days per event
= 1,440,000 gallons per event (4.4 acre-feet per event)

Irrigation Volume = Irrigation Volume Per Event x Number of Events (gallons per season) =1,440,000 gallons/event x 6 events/season
= 8,640,000 gallons per season (26.4 acre-feet per season)

Natural Pond Recharge

Pond Recharge Rate 100 gpm
Recharge Time 24 hours per day

Recharge Volume = Pond Recharge Rate x Recharge Time
(gallons per event) = 100 gpm x 60 minutes/hr x 24 hrs/day x 7 days per event
= 1,008,000 gallons per event (3.1 acre-feet per event)

Recharge Volume = Irrigation Volume Per Event x Number of Events (gallons per season) = 1,008,000 gallons/event x 6 events/season
= 6,048,000 gallons per season (18.5 acre-feet per season)

Minimum Storage Pond = Volume out – recharge
= 26.4 acre-feet – 18.5 acre-feet
Volume Needed = 7.9 acre-feet

Note: Additional evaluation of storage needs might include accounting for losses from evaporation, seepage, or more intensive irrigation (for instance, 2 times per week for several weeks).

Man-made Storage—Design and Construction

Water withdrawals from man-made storage usually require the construction of roads, excavation, hauling, and possibly impoundment construction and a flat surface for the pump. The suction lift from the lowest water surface should be as low as practical. The maximum suction for the pump should match the site; generally, 10 to 15 feet is acceptable.

Excavation will require disposal of the soil material into an area that is not a wetland. The hauling distance of excavation spoils can add significantly to the cost of a dug pond. Bank slopes of man-made storage should be a minimum of 2:1. Special attention needs to be given during design and construction to limit seepage around or under the dam. Impoundments require specification of low permeability materials for the dam core. The low permeability soils need to be compacted properly to minimize water seepage and reduce the possibility of unstable conditions.

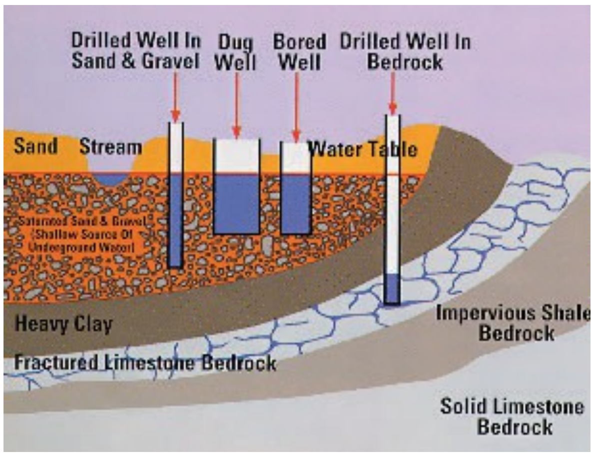
Because of the proximity to surface water, Spill Prevention, Control and Counter Measure (SPCC) Plans should be developed, and necessary containment structures and cleanup materials kept onsite for liquid fuel sources. MDEP or consultants should be contacted for help in developing SPCC Plans.

Proper erosion control practices, such as siltation fencing, hay bales, and soil stabilization by seeding and mulching are required. Timing of pond construction is another important consideration. Spring and fall rainy seasons should be avoided. Contact MDEP, NRCS, local SWCD, or consultants for help with erosion control practices.

Wetland Area, Hans Isaacson

3.9 Groundwater Sources

Groundwater sources include springs, sand and gravel wells, and bedrock wells. In Maine, it has only been within the last several decades that groundwater has been viewed as a significant source of water for irrigation. Pumping can be directly to fields or into a man-made pond storage for later use and possible warming. (Note: Some growers have concerns that the use of cold ground-water may affect plant growth.)



Dug and bored wells typically access shallow ground- water aquifers. Drilled wells access deeper aquifers, such as water-bearing rock formations. (Source: Best Management Practices: Irrigation Management. Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995)

Pumping Groundwater—Spring rates from high-yield wells can range from 50 to over 3,000 gpm. Maine's sand and gravel deposits provide the highest flow rates, ranging up to 3,000 gpm.

Springs occur where the groundwater level intersects the ground surface due to several geologic conditions, including:

- contact springs – water is forced to the surface from a permeable water zone at an interface (contact) with an impermeable zone,
- artesian springs – water is forced under pressure up through breaks in an impermeable layer
- fracture springs – water is flowing from fractures in rock at or near the ground surface.

Contact and artesian springs are probably the most common in Maine. Water from these sources can be extracted by collection systems (pipes and well tiles) or wells placed adjacent to the spring to intercept flow. Individual flowing springs typically provide 50 to 100 gpm. Springs that feed surface water bodies (spring-fed ponds, etc.), though common, are difficult to quantify unless an outflow channel exists, or an estimate of pond volume recovery is made after pumping (see volume-estimating method in Natural Storages.)

Spring flows should be determined to quantify available water before sizing an irrigation system. Flow rate measurements should be made, especially during the dry summer months. Methods used to gauge surface flow in streams or spring channels include:

- volumetric measurement by simply measuring volume and time using a bucket or larger container,
- artificial controls like flumes or weirs, or
- measurement of velocity and area using specialized meters.

Assistance on how to measure flow can be found in USGS publications: http://water.usgs.gov/pubs/twri/twri3-A6/html/pdf.html or contact local conservation agencies or consultants.

Groundwater Wells

High-yield wells are typically classified as two types:

- bedrock wells (common to homeowners throughout Maine)
- sand and gravel wells (sometimes referred to as gravel-packed wells)

The methods used for locating and evaluating these two types differ significantly and generally require the assistance of a qualified hydrogeologist specializing in water supply.

Groundwater—Evaluation of Wells

There are generally four steps to locating, evaluating and designing a well:

- background data collection
- exploratory drilling
- production well installation
- evaluation of safe yield

This section focuses on background data collection, exploratory drilling, and production well installation for bedrock wells and sand and gravel wells, followed by a general discussion of evaluating safe yield of aquifers.

Groundwater—Bedrock Wells

Groundwater in Maine bedrock occurs in cracks or "fractures" in the rock. These fractures are sometimes horizontal, but most often dipping at an angle. Most people are familiar with bedrock wells for home use, which typically yield from 0.5 to 20 gpm. However, high- yield bedrock fractures can yield upwards of 50 to 1,000 gpm. Locating these high-yield fractures takes consulting expertise in geology, photolineament analysis, geophysical measurement and direct exploratory drilling. Actual drilling of these types of wells is commonly done by local well drillers with experience in handling high-yield wells.

The first step in locating a high-yield bedrock well is the review of available hydrologic and geologic reports and maps to better understand the geology, fracture directions, depths to bedrock, and numerous other regional and site-specific features.

Photolineament analysis (also known as fracture trace analysis) interprets linear trends on the earth's surface that may indicate fractures in bedrock. The analysis is done using a stereoscope and pairs of aerial photos to get a three-dimensional view of the ground surface. The analyst looks for depressions, vegetative differences, and other features indicative of fracture traces. Once these potential fracture features are located, various geophysical methods can be used to verify the analysis and locate potential drill sites on the ground.

These geophysical methods measure the contrasting physical or physical-chemical properties of water and earth materials (Driscoll, 1986). The measurements are made at the ground surface or within boreholes to determine water bearing zones, depth to bedrock, and assess types of geologic materials. Some of the most common survey methods used in Maine are seismic refraction, gravity, and electrical resistivity.

Exploratory drilling of 6-inch to 8-inch wells follows, usually with an air rotary drilling rig commonly used to drill residential wells. Because the fracture depth and direction of dip may be unknown, several wells may need to be drilled within a relatively small area to intersect water-bearing fracture zones with sufficient yield. Sustainable pumping yield of the finished well is best determined by performing a multi-day pumping test.

Bedrock production wells should be designed to handle the estimated maximum sustainable yield, considering the water demand, pump size, and cost. Bedrock wells with a larger diameter can significantly add to the well's hydraulic capacity, but evaluation of the sustainable yield should govern design and use.

Groundwater—Sand and Gravel Wells

The highest yielding groundwater wells in Maine are in sand and gravel aquifers in which water occurs in the pore spaces of the material. The more permeable the material, the greater the yield of the well. These deposits can provide flow rates of up to 3,000 gpm.

The first step in locating a high-yield sand and gravel well is the review of available hydrologic and geologic reports and maps to better understand the geology, aquifer thickness, depths to bedrock, and numerous other regional and site-specific features.

Mapped sand and gravel aquifers are located throughout the state as reported by the MGS on its Significant Sand and Gravel Aquifer Maps and associated reports (see the MGS list of publications: https://www.maine.gov/dacf/mgs/pubs/digital/aquifers.htm. However, not all significant sand and gravel aquifers are mapped, and the size and sustainable pumping rates of these aquifers are not known. Therefore, the published maps and reports should be used to provide background information and verified in the field through geophysics and exploratory drilling.

Geophysical methods used when locating bedrock wells are also used for sand and gravel evaluations to determine the thickness of deposits and depths to water.

Exploratory drilling of sand and gravel aquifers is commonly done by well drillers experienced in drive-and-wash drilling techniques using small all-terrain test boring rigs. Drive-and-wash involves driving a 2-inch to 6-inch pipe into the ground and then washing the soil from within the pipe using a rotary bit or bailer. By monitoring the water loss, soil texture, and other indicators, the potential zones to install a well can be determined. Well screens are then installed, and short-term pumping tests are done to determine potential large well yields.

Production wells are usually large-diameter wells (6-inch to 24-inch) which are best installed using a variety of techniques, including:

- cable tool
- dual rotary
- rotary drive-and-wash
- mud rotary

Mud rotary is the least preferred method of those listed, because of the potential for clogging pore spaces.

Sand and gravel production wells are designed to handle the estimated maximum sustainable yield, considering water demand, pump size, and cost. Sand and gravel wells also have a well screen at the bottom that has openings designed to retain a portion of the surrounding soils. Depending on the grain size of the soils, a gravel pack can be placed around the well screen to hold back soils. By removing a portion of the natural soil materials outside the well, the friction losses and water level drawdown at the well are reduced. The fine materials from the surrounding geologic formation are then removed from well screens by a process known as "developing." The most common development methods are:

- surging
- over pumping
- jetting

The longer the sand and gravel well screen, the higher the potential flow rates. Increases in well diameter for sand and gravel wells (as opposed to bedrock wells) do not significantly increase well yield and do not justify the increased cost.

Groundwater—Evaluation of Safe Well Yields

The most important concepts to understand when assessing wells for irrigation are hydraulic pumping capacity versus sustainable well yield. The hydraulic pumping capacity is the maximum flow rate at which a pump can operate for the period of demand without dewatering the well. Sustainable yield is the long-term pumping capacity of the well without dewatering the aquifer. If more water is taken from the aquifer than can be replenished each year, then the well yield is not sustainable.

A first step in evaluating sustainable yield is to evaluate the watershed area that contributes to a well, and the amount of precipitation that can infiltrate to the aquifer through the surface soils. By using surficial soils maps and estimates of recharge rates for different soil types, estimates of aquifer recharge from a watershed can be made. If a well will remove a large volume of the annual groundwater recharge, then other sources or storage should be considered.

Aside from initial recharge estimates, pumping tests are necessary to properly assess sustainable yield. By pumping at a high flow rate (as close as possible to water demand), a hydrogeologist can evaluate:

- potential pumping rates
- water level drawdown
- area of influence (potential impacts)
- whether the aquifer can recharge after pumping

The design of a pumping test consists of determining a constant pumping rate (sustainable over the period of the test), a period (usually 2 to 7 days) and identifying specific wells and surface water locations to monitor. A driller/pump installer commonly rents pumping equipment including a pump, discharge piping, and power source (engine or 3-phase generator). The test is usually run at a constant flow rate, with water levels and stream flow measured at set intervals. After the pump is shut off, the well recovery and monitoring locations are then measured for the same length of time as the pumping test. Analysis of the pumping data is done by a hydrogeologist to determine short-term and sustainable pumping rates, well pumping levels, and potential impacts. These data are then used to size pumps, piping, and possibly storage systems.

Groundwater Limitations

Federal Regulations:

- A permit is not required for water withdrawals from wells for irrigation, unless there are other impacts that trigger a permit (such as wetland impacts or stream dewatering).

State Regulations:

- MDEP: Installation of "significant groundwater wells" is a regulated activity under the Natural Resource Protection Act. However, wells for agricultural use or storage are specifically exempted from the definition of "significant groundwater well" and therefore are not regulated by the DEP.
- LUPC: A permit is required to use any significant volume of water from a well that can impact natural resources such as streams or wetlands.
- Permitting or evaluating groundwater sources to ensure a sustainable resource requires a determination of the safe yield of an aquifer and an understanding of potential impacts.

Groundwater—Construction

A water withdrawal from wells usually requires the installation of test borings, a pro- duction well(s), and, possibly, construction of roads. Wells may have submersible pumps and motors, or pumps may be in the well and motors at the surface (vertical turbine drive pumps). Vertical turbine pumps require a level concrete pad base around the well.

Power sources can include fuel driven generators, engines, or power take-offs from a trac- tor. If fuel driven engines are used, Spill Prevention, Control and Counter Measure (SPCC) Plans should be developed, and necessary containment structures and cleanup materials kept onsite for liquid fuel sources. The MDEP or trained consultants can be contacted for help in developing SPCC Plans. Proper erosion control practices such as siltation fencing, hay bales, and soil stabilization by seeding and mulching are required. Contact MDEP, NRCS, local SWCD, or consultants for help with erosion control practices.

3.10 Water Source Quantity Assessment Considerations

Knowing how much water is available from a water source must be calculated. Calculating the available water for existing ponds, lakes, and dammed streams is simple. For constructed ponds, the size of the pond may be dependent on the recharge source, such as a well or other water diversion. Calculating the quantity of water available for direct withdrawal from rivers and streams can become problematic, given decreasing flow rates through the spring – summer growing season.

Developing a Water Use Management Plan requires an understanding and development of a process for assessing and using water resources. Given the increasing demand for water and concerns about potential adverse impacts on natural resources, growers are advised to include an alternative water source analysis in their Water Use Management Plan that includes efforts to avoid, minimize, and mitigate potential wet- land and aquatic habitats.

To protect the rights of growers and the rights of future water users, federal, state and local governments have created laws and guidelines to ensure an abundant supply of clean water. The regulations and agencies that govern the use of irrigation are listed in Section 6.

3.11 Components of Assessing Irrigation Water Needs

To better understand water management planning, the irrigation water budget, and the Water Management Worksheet, this section contains a general discussion of the following:

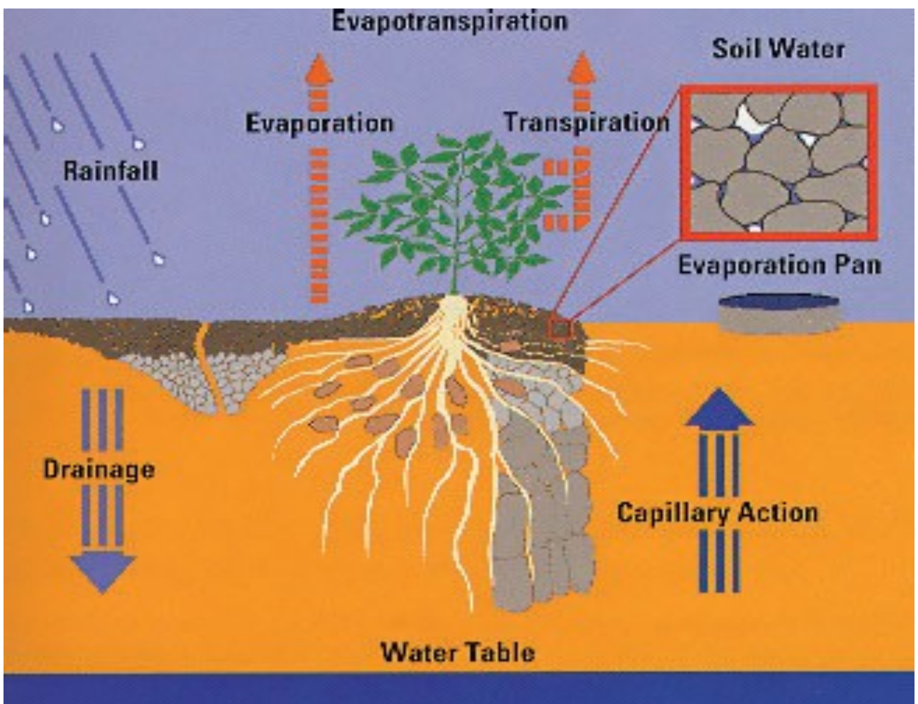
- an explanation of plant water demand,
- how to determine a crop's total consumptive water use,
- how to estimate historical regional precipitation, and
- how to determine how much supplemental water is required through irrigation.

Recommended Management Allowable Depletion (MAD) for Crop Growth Stages				
Crop	**Establishment**	**Vegetative**	**Flowering Yield Formation**	**Ripening to Maturity**
Alfalfa hay	50	50	50	**50**
Beans, green	40	40	40	**40**
Beans, dry	40	40	40	**40**
Corn, grain	50	50	50	**50**
Corn, seed	50	50	50	**50**
Corn, sweet	50	40	40	**40**
Cranberries	40	50	40	**50**
Garlic	30	30	30	**30**
Grains, small	50	50	40	**60**
Grapes	40	40	40	**50**
Grass, pasture/hay	40	50	50	**50**
Grass, seed	50	50	50	**50**
Lettuce	40	50	40	**50**
Nursery stock	50	50	50	**50**
Onions	40	30	30	**30**
Orchard, Fruit	50	50	50	**50**
Peas	50	50	50	**50**
Potatoes	35	35	35	**35**
Sorghum, grain	50	50	50	**50**
Spinach	25	25	25	**25**
Vegetables, 1 to 2 ft root depth	35	30	30	**35**
Vegetables, 3 to 4 ft root depth	35	40	40	**40**

Source: USDA – NRCS National Engineering Handbook , Part 652, Irrigation Guide

Plant Water Demand
Plants need water for growth and cooling. Plant growth requires that sufficient water is available in the soil of the root zone to extract water and nutrients necessary for growth. The percentage of soil water in the root zone that can be lost before the plant is stressed and needs supplemental water through irrigation is known as management allowable depletion (MAD). The MAD value is dependent on soil, crop type, and stage of crop development. Most crops use a MAD limit of moisture content of above 50 percent of field capacity. Soil moisture levels below the MAD value create stress on the plant that may affect crop quality and yield. Consumptive water loss from the soil is a function of two simultaneous and ongoing processes: evaporation from the soil and uptake from plants.

Until the crop is well developed, water loss occurs mostly by evaporation from the soil. As the plant grows and takes up water from the soil, a small fraction is used by the plant. The remainder vaporizes from the plant leaf to the atmosphere, a process known as transpiration. Once the plant is fully developed, most of the water loss occurs by transpiration, which can be as high as 80 percent of the total water loss from the soil. The combined water loss from evaporation and transpiration is known as evapotranspiration (Et).



Evapotranspiration (Et) Cycle (Source: Best Management Practices: Irrigation Management. Ontario (Canada) Ministry of Agriculture, Food and Rural Affairs, 1995)

The factors affecting Et are primarily solar radiation and, to a lesser extent, temperature, wind, and humidity. Understanding evapotranspiration is important for effective irrigation management and water conservation, discussed in Section 5.

Total Consumptive Water Use Additional information needed to size irrigation systems is the total consumptive water use. Total consumptive water use equals the consumptive use per day or week multiplied by the number of growing days or weeks and the crop acreage.

Note: This total is generally an overestimate of plant water use. Experience and judgment are needed in using these estimates for planning and design.

While it can be argued that the recommended criterion for sizing water supplies is the seasonal consumptive use (total plant demand over the growing season), it is unrealistic to assume all water must be (or can be) applied by irrigation. Judgments need to be made on how much water might be expected from precipitation, and the expected frequency.

Precipitation Estimates
Growers need to rely on estimates of historical regional precipitation to determine the supplemental irrigation water needed to meet total consumptive plant use. Estimated seasonal monthly or weekly precipitation medians may be used along with the corresponding peak consumptive use to determine the amount of supplemental irrigation water needed. A source for weather information is the National Weather Service Link: https://hdsc.nws.noaa.gov/pfds/. Sources for historical data are Maine Climate Office or NRCS.

Another method used to estimate precipitation is probability graphs. Probability data on precipitation for Aroostook and Washington counties may be found in Dalton, 2001 and 2002, respectively (see References).

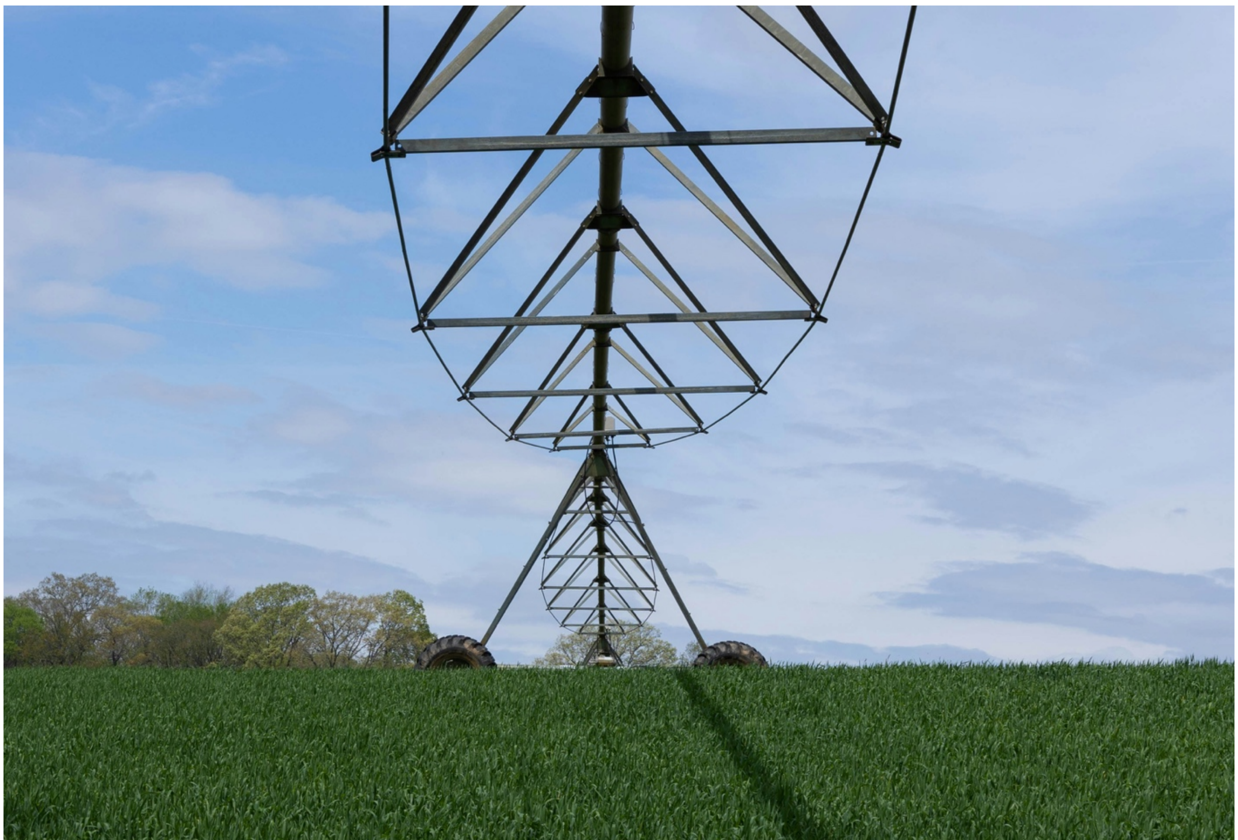
Irrigation Requirements
Irrigation water is the amount of water that must be applied to the crop to replace water lost to evapotranspiration, but not supplied by precipitation. Some irrigation methods (i.e., micro-irrigation) are more efficient than others because evaporation is minimized, especially in arid areas. Examples of efficient irrigation methods include water applied directly to the root zone by drip irrigation and those methods with shorter application periods, such as in-ground small sprinkler systems, with adequate water resources, which allow irrigation during cooler or less windy periods. Highly efficient methods may come with a higher price tag but may also provide a quicker payoff on the grower's initial investment. Manufacturers and irrigation equipment suppliers can supply information on the efficiency rates of specific irrigation equipment (see list of vendors in Appendices).

The following example shows how to calculate the amount of irrigation water needed to meet a specific demand of 100 acres of potatoes irrigated by a center pivot system with an efficiency rate of 80%.

Consumptive use **1.2 inches per week – 0.6 inches per week**
Precipitation
Irrigation

Volume of Irrigation Water Needed = (consumptive use – precipitation) x acreage
Efficiency

= (1.2 – 0.6 inches per week) x 100 acres
0.80



Field Irrigation, Leslie Cross

3.12 Water Source Quality Assessment Considerations

The quality of source water is an important consideration in agricultural water management. For example, water sources can be impacted by road salt or by saltwater intrusion from rising sea levels. Water salinity can adversely affect crop production and soil structure.

PFAS chemicals have affected some Maine farms and water supplies. The Maine Department of Agriculture, Conservation & Forestry's PFAS Response Program can provide further information on PFAS, water testing, and assistance programs.

Coliform bacteria in source water can have an adverse effect on crops and may be subject to regulatory review. The federal Food Safety Modernization Act (FSMA) has affected crop handling practices on many farms. Farmers using irrigation should be aware that irrigated crops may be subject to FSMA rules. Further information is available from the Maine Department of Agriculture, Conservation & Forestry's Division of Quality Assurance & Regulations.

4. Irrigation Application Systems

The main principle of irrigation is quite simple: to provide the root zone of the crop with usable amounts of water during periods of need. Application systems accomplish this goal by delivering irrigation water to a field and then distributing it within the field.

The size and type of an irrigation system is primarily dependent on the available water source(s). For example, if water is limited, a grower's decision to partially irrigate the entire crop or fully irrigate a portion of the crop can become an economic decision of crop quality versus quantity. In this section, components of irrigation systems are described and evaluated to help growers choose the best system for their operation.

4.1. Irrigation System Components

Every irrigation system has some form of the following components, which must be suitably matched:

- water source
- power source
- pumps
- conduit pipe
- filtrations
- emission points, e.g., sprinklers
- water-efficient hardware
- Sensors (difficult to install)
- Remote and mobile controls (Wifi / Bluetooth)

Irrigation systems generally consist of four major components:

- pumps
- piping
- application hardware
- application software

Pumps

A major component of any irrigation system is the pump. Water must be delivered to all sprinklers or emitters at the proper pressure and flow rate. The pump and motor must be adequately matched to perform the desired function. A proper match will ensure an economical system that can reduce maintenance and operation costs.

Pumps have many uses. They are usually located at the water source but may be augmented by other pumps along the piping system to boost pressure. Pumps are also used for high flow applications such as refilling storages.

Each irrigation pump has unique flow characteristics that vary with pump rpm and operating pressure. The pump must be matched to three important irrigation parameters:

- Total irrigation flow rate at any one time is determined by the flow rate from the maximum number of sprinklers or emitters that operate at the same time.

- Brake horsepower (HP) required by an irrigation pump can be calculated from:
    - HP = Q x (H/3960) x E.

Pump efficiency can be obtained from a Pump Performance Curve. This curve indicates how the pump performs at different pumping rates, rpm speed, and different resistant forces (H). The higher the efficiency, the more energy that is transferred to the water for movement.

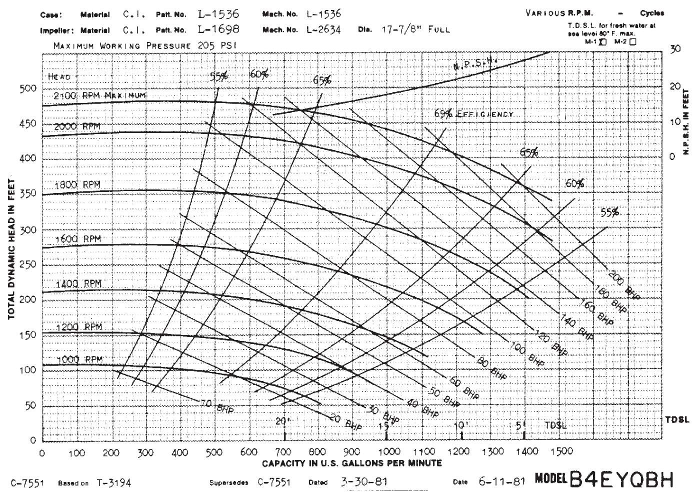
Total dynamic head (H) developed by the system H = Hp + Hf + Hs + He
(Hp = pressure head; Hf = friction head; Hs = static suction head; He = static discharge head)

HP = brake horsepower required by the system
Q = design flow rate of system (gpm) H = Total Dynamic Head (ft)
E = Pump efficiency (% in decimal form)

Pumps used in Maine irrigation systems can range from 5 to 5,000 gallons per minute (gpm), depending on the acreage served and the type of application system. Electricity or fuel-driven engines, including power take-offs from tractors, may be used to run irrigation pumps. Maine certified pump installers must install and maintain well pumps.

- Most growers use centrifugal surface pumps to draw water from surface sources (ponds, streams, etc.). These pumps are limited by how high they can lift water.
- Pumping from wells with water levels greater than 20 feet below ground generally requires the use of submersible pumps.
- Line shaft turbine pumps are used on high yield wells and require installers that specialize in these types of pumps.

Growers are advised to obtain expert advice when selecting a pump.



Piping

Piping is separated into two categories: transmission piping and distribution piping. Transmission piping is the largest diameter piping required to transport water long distances without causing excessive pressures or "head loss". Head loss in piping is caused by friction between the water and piping surface. Excessive head loss will limit flow in the piping and result in increased pumping costs. In many cases, the additional cost of large diameter piping provides a short-term payoff in power and fuel cost savings. Transmission piping can range from 2 inches to 2 feet in diameter. In above-ground portable systems, these are commonly 4-, 6-, or 8-inch-diameter aluminum pipes. Buried pipes are generally plastic, HDPE or PVC.

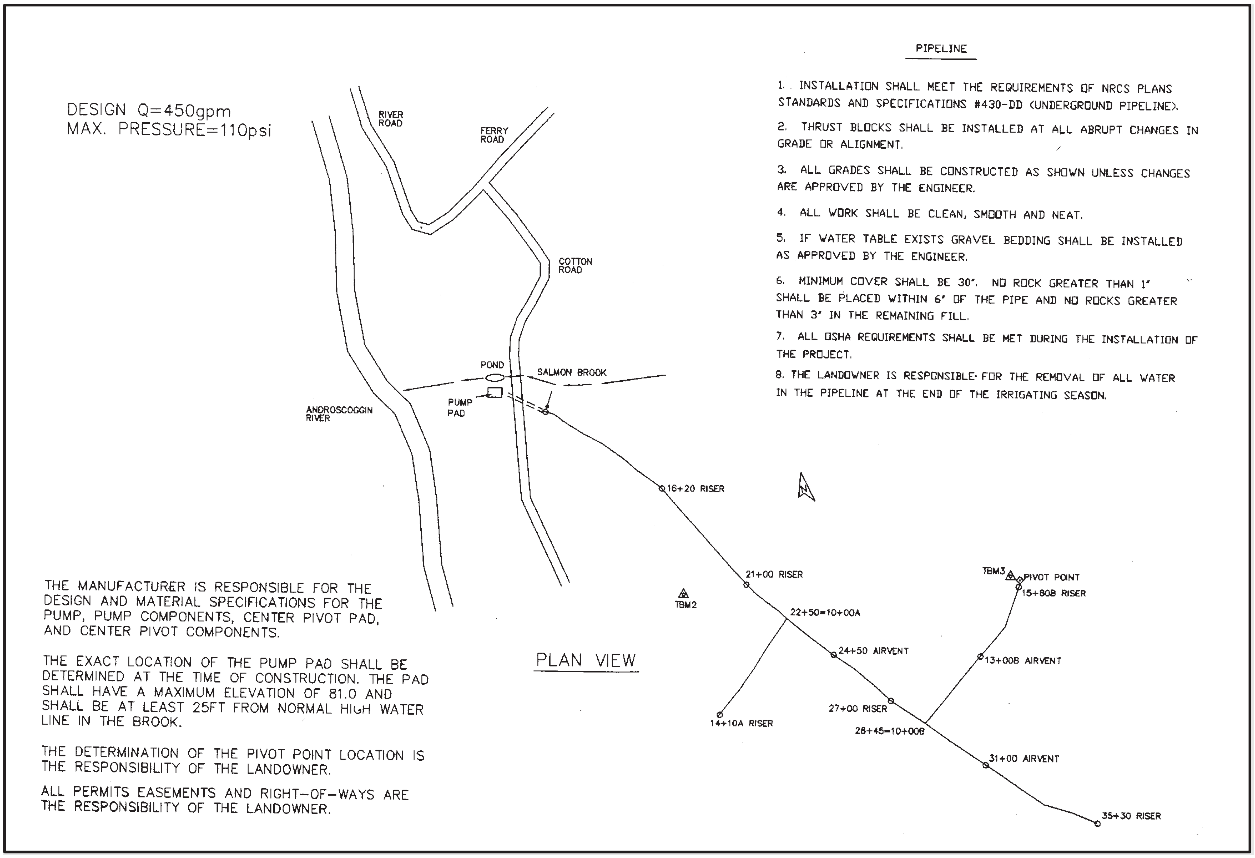
Distribution piping moves the water to the application hardware (nozzles, emitters, etc.). These pipes are generally smaller in diameter than transmission piping to handle the lower flow rates but must be large enough to ensure that the pressure at the end of the system is adequate for the applicator. Solid set distribution piping systems are permanent below-ground or seasonally set-up above-ground piping systems.

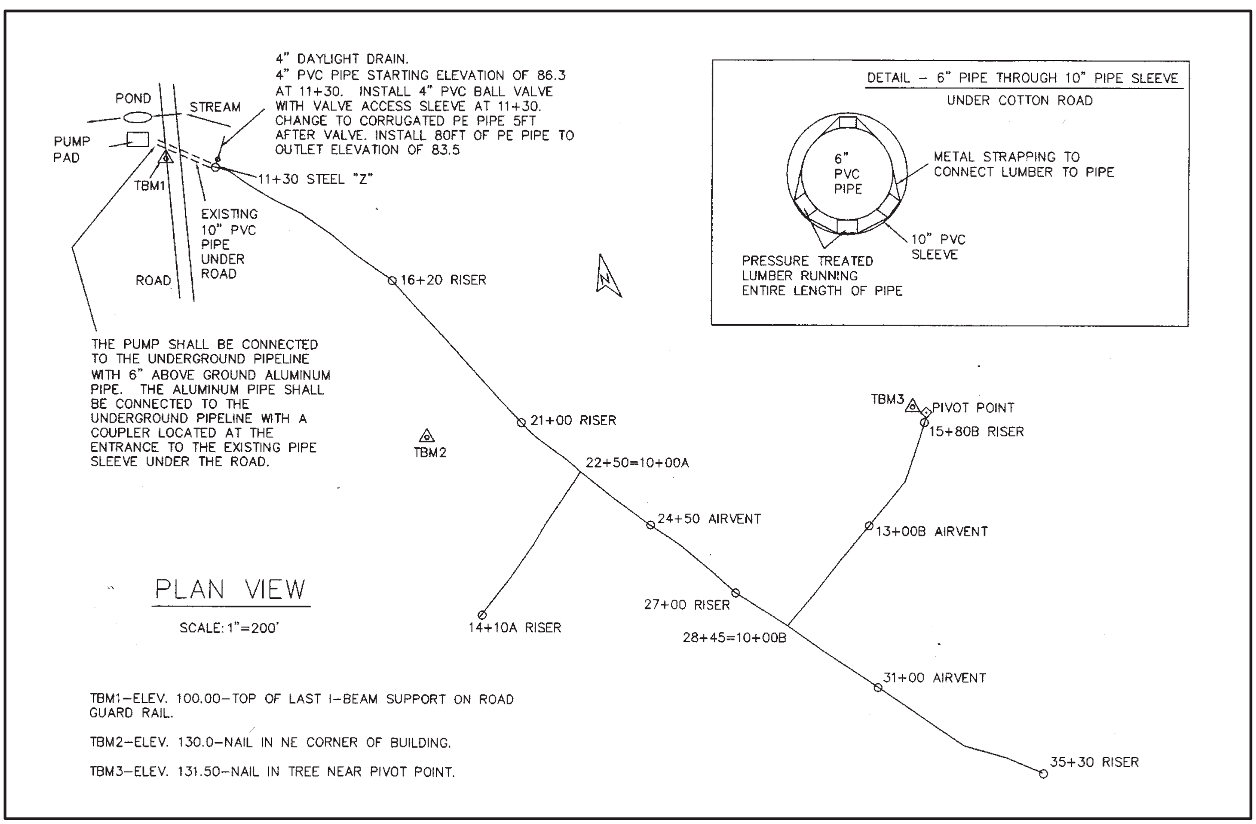
Piping needs to be designed according to required pumping rate and pressure. Pressure relief valves, air vents, thrust blocks, and their appurtenances may be needed to protect the pipe. NRCS irrigation water conveyance standards or other irrigation industry standards should be followed.

Friction Loss Calculator: [Friction Loss Calculators (wsu.edu)](http://irrigation.wsu.edu/Secondary_Pages/Irr_Calculators/General/G_FrictionLoss.php)
http://irrigation.wsu.edu/Secondary_Pages/Irr_Calculators/General/G_FrictionLoss.php

Note

Improper sizing of pumps and piping is a major cause of under- or over- application of water. This is especially true for portable systems where pumping distance and changes in elevation vary from field to field.


PIPELINE
1. INSTALLATION SHALL MEET THE REQUIREMENTS OF NRCS PLANS STANDARDS AND SPECIFICATIONS #430-DD (UNDERGROUND PIPELINE).
2. THRUST BLOCKS SHALL BE INSTALLED AT ALL ABRUPT CHANGES IN GRADE OR ALIGNMENT.
3. ALL GRADES SHALL BE CONSTRUCTED AS SHOWN UNLESS CHANGES ARE APPROVED BY THE ENGINEER.
4. ALL WORK SHALL BE CLEAN, SMOOTH AND NEAT.
5. IF WATER TABLE EXISTS GRAVEL BEDDING SHALL BE INSTALLED AS APPROVED BY THE ENGINEER.
6. MINIMUM COVER SHALL BE 30". NO ROCK GREATER THAN 1" SHALL BE PLACED WITHIN 6" OF THE PIPE AND NO ROCKS GREATER THAN 3" IN THE REMAINING FILL.
7. ALL OSHA REQUIREMENTS SHALL BE MET DURING THE INSTALLATION OF THE PROJECT.
8. THE LANDOWNER IS RESPONSIBLE FOR THE REMOVAL OF ALL WATER IN THE PIPELINE AT THE END OF THE IRRIGATING SEASON.
DESIGN Q=450gpm
MAX. PRESSURE=110psi
RIVER ROAD
FERRY ROAD
COTTON ROAD
POND
SALMON BROOK
PUMP PAD
ANDROSCOGGIN RIVER
16+20 RISER
21+00 RISER
TBM2
TBM3
PIVOT POINT
15+80B RISER
22+50=10+00A
24+50 AIRVENT
13+00B AIRVENT
27+00 RISER
14+10A RISER
28+45=10+00B
31+00 AIRVENT
35+30 RISER
PLAN VIEW
THE MANUFACTURER IS RESPONSIBLE FOR THE DESIGN AND MATERIAL SPECIFICATIONS FOR THE PUMP, PUMP COMPONENTS, CENTER PIVOT PAD, AND CENTER PIVOT COMPONENTS.
THE EXACT LOCATION OF THE PUMP PAD SHALL BE DETERMINED AT THE TIME OF CONSTRUCTION. THE PAD SHALL HAVE A MAXIMUM ELEVATION OF 81.0 AND SHALL BE AT LEAST 25FT FROM NORMAL HIGH WATER LINE IN THE BROOK.
THE DETERMINATION OF THE PIVOT POINT LOCATION IS THE RESPONSIBILITY OF THE LANDOWNER.
ALL PERMITS EASEMENTS AND RIGHT-OF-WAYS ARE THE RESPONSIBILITY OF THE LANDOWNER.


4" DAYLIGHT DRAIN.
4" PVC PIPE STARTING ELEVATION OF 86.3 AT 11+30. INSTALL 4" PVC BALL VALVE WITH VALVE ACCESS SLEEVE AT 11+30. CHANGE TO CORRUGATED PE PIPE 5FT AFTER VALVE. INSTALL 80FT OF PE PIPE TO OUTLET ELEVATION OF 83.5
POND
STREAM
PUMP PAD
TBM1
11+30 STEEL "Z"
EXISTING 10" PVC PIPE UNDER ROAD
ROAD
16+20 RISER
DETAIL – 6" PIPE THROUGH 10" PIPE SLEEVE UNDER COTTON ROAD
6" PVC PIPE
METAL STRAPPING TO CONNECT LUMBER TO PIPE
10" PVC SLEEVE
PRESSURE TREATED LUMBER RUNNING ENTIRE LENGTH OF PIPE
THE PUMP SHALL BE CONNECTED TO THE UNDERGROUND PIPELINE WITH 6" ABOVE GROUND ALUMINUM PIPE. THE ALUMINUM PIPE SHALL BE CONNECTED TO THE UNDERGROUND PIPELINE WITH A COUPLER LOCATED AT THE ENTRANCE TO THE EXISTING PIPE SLEEVE UNDER THE ROAD.
TBM2
21+00 RISER
TBM3
PIVOT POINT
15+80B RISER
22+50=10+00A
24+50 AIRVENT
13+00B AIRVENT
PLAN VIEW
SCALE: 1"=200'
14+10A RISER
27+00 RISER
28+45=10+00B
31+00 AIRVENT
35+30 RISER
TBM1–ELEV. 100.00–TOP OF LAST I-BEAM SUPPORT ON ROAD GUARD RAIL.
TBM2–ELEV. 130.0–NAIL IN NE CORNER OF BUILDING.
TBM3–ELEV. 131.50–NAIL IN TREE NEAR PIVOT POINT.

4.2. Application Hardware

There are many choices for application hardware but, in general, the technology can be grouped into three basic delivery methods for the in-field distribution of water:

- big guns (includes center pivots),
- small sprinklers, and
- micro-irrigation (spray, drip or trickle).

Big Guns
Big guns represent one type of the sprinkler irrigation method that sprays water over the entire soil surface of the field. Guns deliver water to the crop in the form of a high-trajectory stream that breaks up before reaching the ground or crop. They are useful for delivering a large volume of water over a large area. Flow rates from individual guns are very high and range from 50 to 500 gpm and can individually cover 1/2 to 3 acres. In Maine, 1 to 12 guns are commonly used at one time, dependent on the water source, pumps, and available labor.

Advantages:
- Water application times are the shortest of the three types, to provide equivalent soil moisture change.
- Big guns can be set-up on movable or buried pipe (with risers), hose travelers, stands with flexible hose, or at the ends of traveler or center pivots.
- Capital cost is low.

Disadvantages:
- Big guns are affected by wind, due to the high trajectory of the water.
- On larger fields, they may need to be manually moved after each application to cover the entire field.
- Labor costs are higher to move big guns, as opposed to fixed application hardware (sprinklers and micro-irrigation).
- Large droplet size
- Higher potential for soil erosion

Small Sprinklers
Small sprinklers also deliver water over the entire soil surface of the field. However, they are designed to provide a lower flow rate (1 to 7 gpm) and a longer application time and cover a smaller area (0.1 to 0.2 acres). Small sprinklers can be installed on solid-set distribution piping (above-ground or below-ground), on center pivots, or lateral move traveler systems.

Advantages:
- Applications are close to the ground, which minimize evaporation from heat and wind, and allow for more even distribution.
- Lower potential for soil erosion

Disadvantages:

- Because of the intensive distribution of piping needed, permanent fixed systems are best installed with buried piping.
- Capital cost is moderate to high.

Micro-irrigation

Micro-irrigation pipes the water directly, applying the water to the soil near the base of each plant or into the soil below the root zone, either by spray, drip, or trickle application. The flow rates for each plant are relatively slow, 0.5 to 2 gpm. It is most used for high-value fruit trees, cultivated berry crops, vegetables, ornamentals, and nursery applications.

Advantages:

- Most water-efficient because water is applied to a smaller area and stays closer to or in the ground,
- Lower potential soil erosion,
- Lower pressure requirements, and
- Micronutrients easily applied.

Disadvantages:

- This equipment is only feasible for certain crops because, for maximum efficiency, piping is left in place for several years on or below the ground surface, preventing tilling.
- Micro-irrigation cannot be used at every location because it requires a clean water source and/or filtration to remove particles.
- Capital cost is high.

4.3. Fixed or Portable Systems

The choice between installing a fixed system or portable system is a function of:

- capital costs to install,
- labor and maintenance costs to operate,
- time to complete an irrigation application,
- location and amount of avail- able water supply, and
- value of the system on rotation crops.

The difference between fixed or portable irrigation systems is the type of piping net- work used to supply water to the irrigation application hardware.

Fixed Systems

Examples of these systems are micro-irrigation, in-ground piped small sprinklers, in- ground piped big guns, above-ground piped big guns, and center pivots.

The buried pipelines in fixed systems reduce or eliminate the need for labor to move pipes within the fields. In addition, fixed systems may include a dedicated pump. These types of systems require minimum labor and can be true turnkey systems.

Portable Systems

In Maine, these include many variations of portable components including pumps, transmission piping, and distribution piping. Examples of these systems are hose reels, above-ground big guns, and some small, lateral moving travelers.

The most common portable systems require that the transmission and distribution piping be moved with each application. While this may work well on small farms where fields are located close together, this system is very labor-intensive for larger farms that may have difficulty keeping up with plant demand during peak consumptive-use periods. In addition, portable piping systems require large quantities of additional pipe to be available to guarantee that transmission and distribution are ahead of actual irrigation. This is especially true for big gun above-ground piping systems. Hose reel systems generally require less labor than hard-pipe-moved systems.

4.4 Selecting an Irrigation System

Choosing the right irrigation system from the hardware discussed in this section is a challenging and complex task and is fundamental to a successful irrigation practice. Growers must carefully match the design to crop needs, site and soil conditions, irrigation schedules, available water supply, capital available for equipment purchase, and labor demands. The design will likely go through several modifications to make sure all these aspects are addressed.

This process requires more than grower experience. Growers are advised to work with experts to design their irrigation system. Refer to the Appendices for a resource listing of vendors and consultants.

Irrigation System Management Considerations

Good management of an irrigation system can help reduce water use and increase energy savings, thereby improving profitability. Periodic inspection of the system as well as maintaining the equipment will help minimize problems. The following steps should be followed:

- Clean and inspect the pump annually, including the packing, seals, and foot valves.
- Use a filter basket on the suction line to prevent foreign objects from damaging the pump and limit clogging of sprinkler nozzles.
- Check for line leaks. System operating pressures should fall within spec ranges.
- Check periodically for uniform water application patterns and rates.

Irrigation System Design Considerations for Conservation

Irrigation system design and efficiency are critical components of a Water Use Management Plan as discussed in Section 3.

It is critical to choose equipment that minimizes water usage and fits the needs of the crop to reduce the total water needs for the farm, which may save money in terms of the size of pumps and storages to be built. In general, growers should keep in mind the suitability of certain equipment for specific types of soils and terrains:

- Low pressure center pivots are best suited to flat terrain and soils with high infiltration rates.
- High pressure center pivots are best suited to rolling terrain.
- Big gun irrigation is most suited to sandy soils and flat terrain where runoff potential is less.
- Portable piping and solid-set sprinkler-system design is adaptable enough to accommodate a wide range of soil conditions and terrain.
- Drip irrigation and other low-volume systems are particularly well suited to steeper slopes and heavier soils. These systems are also ideal where water supplies are limited, and runoff potential is high.
- Special systems must be purchased for greenhouse operations, nurseries, and cranberry operations.

Other equipment considerations include proper sizing of piping to save energy and reduce operating costs, and using lower pressure nozzles that will also reduce energy use. Growers are advised to work with a consultant, extension agent and/or equipment manufacturers for help in selecting the best equipment for their situation to maximize energy efficiency and water conservation. System design should incorporate NRCS irrigation standards, specifications, and design criteria or irrigation industry standards.

4.5 Noise Control for Irrigation Systems

Noise from irrigation systems can sometimes present a problem for irrigators and their neighbors. Although the pump radiates some noise, the major source of noise is the driving motor.

Irrigation equipment noise levels can be substantially reduced by:

- if possible, shutting down irrigation during the night when noise interferes with sleep;
- installing exhaust and inlet silencers on engines that currently do not have them;
- using an electric motor drive instead of internal combustion engine where feasible;
- erecting an acoustic barrier that blocks the line of hearing from the engine exhaust, inlet and casing toward the area to be protected from noise;
- facing the inlet and outlet ducts away from the area to be protected; and
- selecting a location where noise does not naturally carry, such as depressions in the terrain, away from large bodies of water with dwellings.

5. Conservation Practices and Irrigation Scheduling

The goal of irrigation is to provide a crop with the right amount of water, when the crop needs it for maximum crop response, at the lowest cost, and with least impact on the environment. By controlling the crop's water supply, growers are controlling an essential production variable.

To do this effectively, it's worth looking at some basic principles:

- how to use conservation practices to save water,
- how soils provide moisture to crops,
- how much water crops require and when they need it,
- how water flows through, over, and around cropland, and
- how to estimate and schedule crop water requirements practically and at low cost.

5.1 Conservation Practices

The goal of every grower is to practice irrigation management to fulfill water needs profitably, safely, and in an environmentally responsible way. Irrigation depends on reliable supplies of fresh, clean water from surface and/or groundwater sources. In developing the Water Use Management Plan (see Section 3), growers must be aware of potential impacts that the selected irrigation system may have on the quantity and quality of surface and groundwater. While a main purpose of a plan is to document the grower's decision to support an efficient and cost-effective application of supplemental water to maintain or improve crop yield and quality, regulations require that growers plan for limiting withdrawal of water from natural water bodies during low-flow periods.

IRRIGATION CONSERVATION AND SOIL MANAGEMENT PRACTICES

Build healthy soils to allow water to infiltrate and be available for crop use:

- Add organic matter (manure, green manure, compost, cover crops): the soil's structure will improve and the amount of water available to the crop will increase.
- Avoid compaction: don't work soil when wet, especially heavier soils.
- Reduce tillage: less tillage means less drying and less organic matter loss. Try reservoir tillage: it holds water at the soil surface for infiltration.
- With reduced tillage and higher organic matter, earthworm population will increase.

Irrigate efficiently:

- Harvest water from watercourses during peak flow, or from groundwater when water table is high.
- Sprinkle irrigate when winds are low.
- On small field areas choose drip irrigation at the next equipment upgrade.
- Apply the right amount of water when the crop needs it; use irrigation scheduling.
- Minimize sprinkler irrigation during the heat of the day.
- Maintain equipment for peak performance.

Reduce water loss from crops and soil (evapotranspiration):

- Plant windbreaks or wind strips to slow drying winds.
- Plant perennials into chemically killed sod.
- Use dwarf grasses between orchards and nursery crops.
- Schedule short season crops for spring and fall.
- Manage crop residues to reduce runoff, increase infiltration, and so they can act like mulch.
- Space plants to cover soil surface quickly and use plastic or organic mulches.
- Control weeds early.
- Mow sod and cover crops regularly.
- Some tillage can be beneficial under dry conditions. A soil mulch layer can reduce soil evaporation in some circumstances, e.g., vegetable on muck soils, and strawberries on mineral soils.

When drawing water for irrigation, growers must ensure there are no long-term implications for the local environment, and no short-term interference with other uses. More specifically, growers need to know:

- an estimate of how much water might be needed,
- the repercussions if adequate water isn't available,
- how continuous the supply is (or the recharge rate), especially during the time of need when conditions are the driest and supplies are usually the lowest,
- that the quality of water matches the needs of the crop to be irrigated,
- how the location of the water supply impacts the design and cost of the irrigation system, i.e. horizontal distance and vertical lift,
- if the amount of water being taken is environmentally sustainable,
- effects on fish and fauna – a large suction inlet cuts down on water velocity entering the intake pipe, and allows fish to escape in special circum- stances,
- effects on quality and quantity of water in adjacent bodies of water, and
- effects on the water table.

5.2 Estimating Water Needs and When to Irrigate

Water Balances: Rainfall and Crop Requirements

Knowing how water moves through soils can help growers use irrigation water more effectively with less risk to water sources. Water is added to soils as snow, snowmelt and rain. In a typical field, a large percentage of rainfall is eventually evaporated back to the atmosphere. Depending on the precipitation intensity and the soil infiltration rate, a percentage of the water may run off the soil surface to streams, brooks, drains, lakes, and ponds. The remaining precipitation will enter ('infiltrate') the soil. This soil water can be stored as soil moisture and be taken up by plants, evaporate back to the atmosphere, or percolate through the soil to groundwater. The groundwater can also replenish the soil water table (in shallow aquifers), percolate to deeper aquifers, or dis- charge to surface waters such as streams and ponds.

Different crops have different water needs, but in general, precipitation ranges in Maine do not meet plant demand, even in an average year. Potatoes have a demand of approximately one inch per week, and crop water requirements may be 12 to 15 inches during the growing season, June to September. However, precipitation during this same period averages only 12 inches per season with an observed range of 7 to 14 inches (see Dalton, 2003). This results in a total water deficit for the potato crop even in an average year. Unfortunately, years of below-average rainfall occur, causing even greater moisture deficits.

Wild blueberries also demand at least 1 inch of water per week in the fruit bearing year. With their longer growing season, wild blueberries have crop water requirements in a bearing year of 10 to 15 inches during their growing season, May to September. However, precipitation in Downeast Maine during this same period averages only 6.5 5 – 3 inches per season with an observed range of 3 to 16 inches (Jonesboro Station, 1948 to 1999). This results in a water deficit for the Downeast wild blueberry crop in an average year.

Soil Water

Each soil type and field have two unique characteristics: water intake rate and available moisture capacity. These determine how much water is held in the soil and how available the water is for plant growth. Growers can use this information, along with specific plant water demands and recent area rainfall amounts, to determine crop water requirements and the optimum schedule for irrigation.

Water Intake Rate (or infiltration rate): how fast the soil can absorb water.

To be efficient and cost-effective, the goal during irrigation is to avoid wasting water during application. Growers need to know the water intake rate of the soil. This is the rate at which water infiltrates the soil and it determines how much water to apply per hour. The following table lists the maximum rate of water to apply per hour for various soil types. Coarse-textured soils have a higher water intake rate than fine-textured soils.

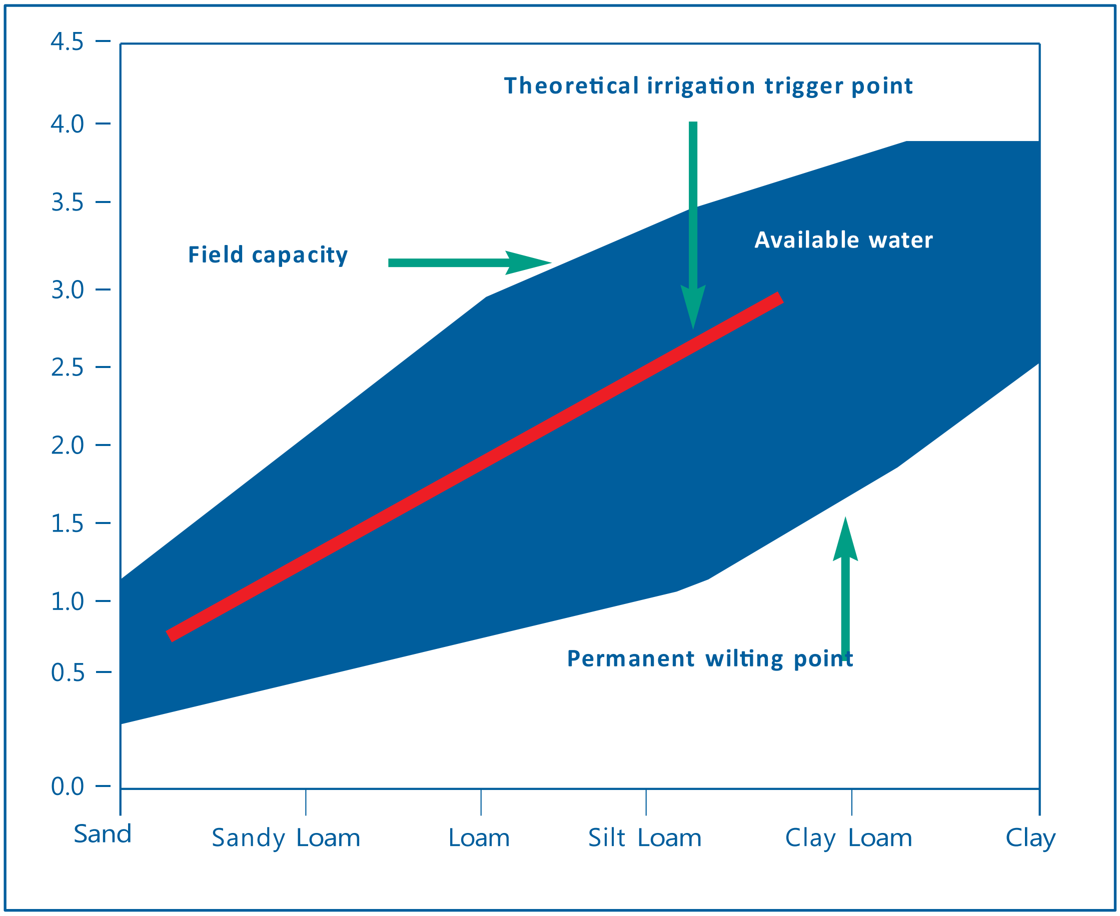
- Water infiltrates coarse-textured soils faster than fine-textured ones.
- Good soil structure improves infiltration–soil aggregate formation is the key, especially in loams, silt loams and clays.
- Cover crops or crop residues can protect soil and slow runoff, increasing water intake rate and maintaining soil structure at the same time.
- Slope, soil compaction and tillage practices also affect speed of water movement into the soil.
- In heavier soils, a grower may chisel the trough between tilled rows to improve water infiltration.
- The presence of high populations of earthworms can have a very beneficial effect on water infiltration rates.
- Water applied faster than a soil's intake rate can result in ponding, leading to runoff erosion and wasted irrigation water.

AVAILABLE MOISTURE CAPACITY AND INTAKE RATE FOR SOILS				
	Available Moisture Capacity (in. water / in. soil)		Intake Rate (in./hr)	
Soil Texture	RANGE	AVERAGE	RANGE	AVERAGE
SANDS	0.05-0.08	0.065	0.5-1.0	0.70
LOAMY SAND	0.07-0.10	0.085	0.3-0.8	0.55
SANDY LOAM	0.09-0.12	0.11	0.3-0.8	0.55
LOAM	0.13-0.17	0.15	0.3-0.8	0.55
SILT LOAM	0.14-0.17	0.16	0.2-0.3	0.25
SILT CLAY LOAM	0.15-0.20	0.18	0.2-0.3	0.25
CLAY LOAM	0.15-0.18	0.17	0.2-0.3	0.25
CLAY	0.15-0.17	0.16	0.1-0.25	0.20

The application system should be sized to take advantage of the maximum intake rate of the soil to minimize irrigation time, but not to exceed the water supply rate. If water is applied at rates exceeding the intake rate, then runoff may occur. For example, in fields where the soil is high in clay, excessive application could result in wasted water with little benefit to crops as water runs off or evaporates from the field. For fields with soil high in sand, where water is absorbed more quickly into the soil, need- ed water can be applied in a shorter period, allowing more acreage to be covered in less time. Rain or irrigation gauges should be placed in the field to help determine how much irrigation water has been applied. For more information about water intake rates and available moisture capacity for specific Maine soil types, refer to the Appendices, or consult with local conservation agencies.

Most crops have certain growth stages when drought stress can severely reduce yield and/or quality. While adequate moisture is desirable at all growth stages, irrigation is especially important during the critical growth periods. Using simple monitoring methods and calculations, scheduling can make irrigation more timely, more precise and less wasteful.

Typical water-holding capacities of different textured soils
(Maximum available water occurs in the silt loam soil)



Available Moisture Capacity (the amount of water a soil can hold that is available to the crop)

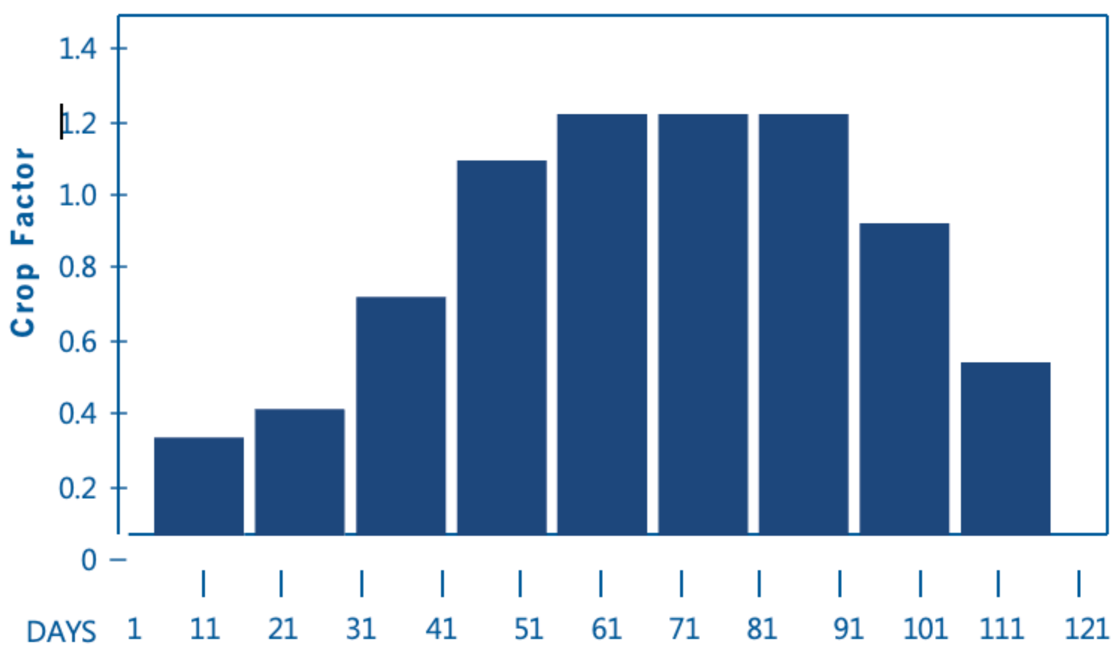
Soil texture and the percentage of organic matter determines how much water a soil can hold – what the crop can use is called available soil water, and how much is bound to the soil but unavailable is called bound water.

- Coarse-textured soils hold less water, so watering must be more frequent.
- Field capacity is the amount of water held in a soil after the excess has drained from a completely saturating rainfall.
- The permanent wilting point is the amount of water held in the soil below which plants wilt and do not recover.
- (Note: Crop yield and quality losses can occur before the permanent wilting point.)

Plant Water Requirements
The available water in the soil is used by a combination of plant transpiration and soil evaporation, i.e., evapotranspiration (Et). The available water can be expressed as inches of water per inch of soil depth.

Temperature, light intensity, wind, humidity, crop cover, and crop growth stage all affect the plant water demand. The maximum Et, for use in irrigation scheduling, can either be estimated using evaporation data available from a local weather station, or from on-site instrumentation. The evaporation values are modified by a crop factor (based on the type of crop and its stage of development) to determine Et. The crop factor varies depending on the type of crop (crop species, annual vs. perennial) and the crop growth stage. For annual crops, the crop factor increases from emergence up to 50 to 80 percent crop cover, remains at a maximum for 2 to 5 weeks, and then decreases.

Typical crop factors over a season are depicted in the preceding graph. The moisture needed to supply the crop's Et needs is called the crop water requirement. Water depleted from the soil by Et is normally replenished by rain, dew, or irrigation in sufficient amounts to meet the crop need at any given time. Irrigation should maintain a minimum amount of available soil moisture: if water isn't applied until the crop is wilting, economic losses have already occurred, as yield and/or quality potential will be reduced. Frequency and depth of irrigation required varies, depending on soil characteristics, crop water requirements, and rooting depth.



This generalized graph above depicts changing crop factors during a season. Crop factors are used to adjust reference Et values to estimate daily crop consumptive use.

5.3 Irrigation Scheduling

Irrigation scheduling is the process of planning and providing crops with the amount of water needed when they need it. It can involve monitoring, record keeping, and the necessary calculations to determine field water capacity and soil water balance. Ultimately, the grower compensates for net losses with irrigation.

Benefits of Scheduling
Scheduling allows more efficient use of water resources and more efficient use of equipment, management time and labor. The yield and quality is increased, and there are better returns on investment of irrigation equipment. It also optimizes application timing, which prevents crop moisture stress and potential damage to yield and quality. Scheduling also reduces the possibility of excess moisture that will lead to leaching or runoff, because the water-holding capacity of the soil is known and will not be exceeded.

Methods of Determining When to Irrigate
The need for irrigation is based on one or more of the following criteria:

- soil moisture based on hand feel or sensing equipment,
- evapotranspiration (consumptive crop use), and
- crop symptoms of water stress (not recommended)

Each method has its advantages and disadvantages.

Soil Moisture
Using soil moisture measurements, a limit is set on the depletion of available soil water in the crop-rooting zone. For example, the allowable available soil moisture depletion level may be set at 50 percent, and irrigation is scheduled to keep available soil water in the root zone above that level.

The allowable available soil moisture depletion can vary through the growing season. Soil moisture may be allowed to drop lower as the growing season progresses and the critical periods of crop development pass. In addition, over watering can cause blight on potatoes, or rupture the skins during freezing in the situation of processing berries.

Soil moisture can be measured by:

- hand feel method,
- gravimetric measurement, and
- soil moisture sensors.

Hand Feel Method
The hand feel method involves a probe or shovel to obtain soil samples at a desired depth. While it is the quickest and simplest method, due to subjectivity, it is not especially accurate. Accuracy can be improved over time by comparing hand feel samples with sensing equipment.

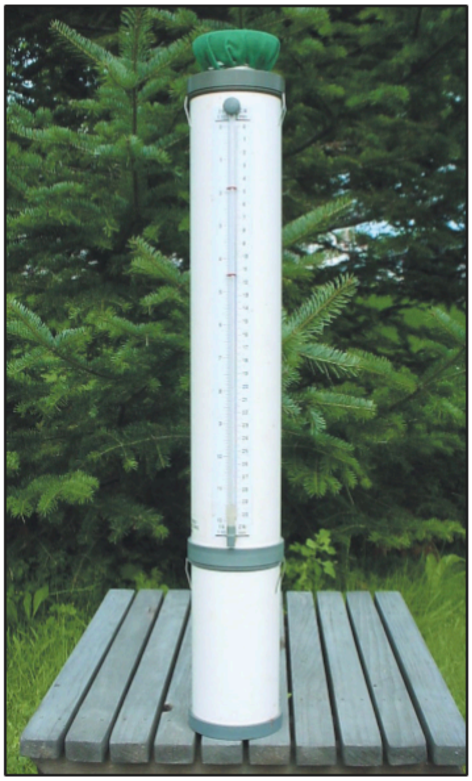
The table below has been used for some time as a guide in judging soil moisture. It relates soil appearance and feel to approximate soil moisture levels for specific soil groups.

GUIDE FOR ESTIMATING SOIL MOISTURE BY THE FEEL METHOD TABLE

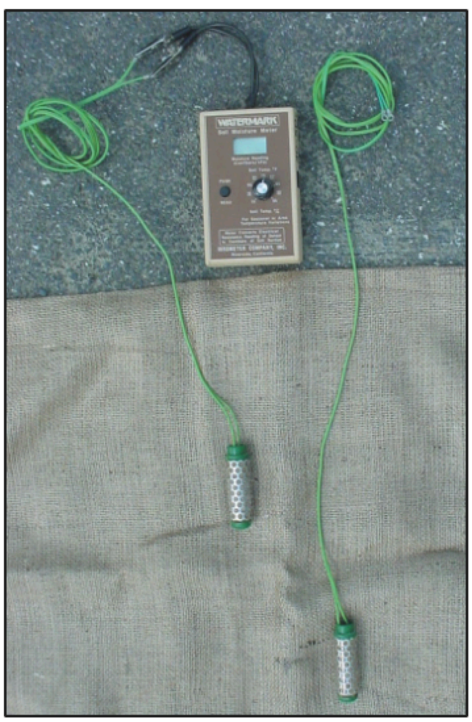
Available Moisture in Soil	Coarse (sands)	Mod. Coarse (sandy loams)	Medium (silt loams, loams)	Fine /Very Fine (clay, clay loams)
0%	Dry, loose and single grained; flows through fingers	Dry and loose; flows through fingers	Hard clods that break into powder	Hard, baked and cracked; has loose crumbs on surface in some places
50% OR LESS	Appears to be dry; does not form a ball under pressure	Appears to be dry; does not form a ball under pressure	Somewhat crumbly but holds together under pressure	Somewhat pliable; balls under pressure
50-75%	Appears to be dry; does not form a ball under pressure	Balls under pressure; but seldom holds together	Forms a ball under pressure; somewhat plastic; sticks slightly under pressure	Forms a ball; ribbons out between thumb and forefinger
75% TO FIELD CAPACITY	Sticks together slightly; may form a very weak ball under pressure	Forms weak ball that breaks easily; does not stick	Forms ball; very pliable; sticks readily if relatively high in clay	Ribbons out between fingers easily; has a slick feeling
AT FIELD CAPACITY (100%)	On squeezing, no free water appears on soil but wet out- line of ball is left on hand	Same as for coarse-textured solids at field capacity	Same as for coarse-textured solids at field capacity	Same as for coarse-textured solids at field capacity
ABOVE FIELD CAPACITY	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface

DETERMINING SOIL MOISTURE BY HAND FEEL METHOD

Coarse (Sands)		Medium (Silt Loams)
	50% or less	
	50 – 75%	
	75% – Field Capacity	
	Field Capacity	



Atmometer measures evapotranspiration.



Watermark sensor is a type of electrical resistance block.

Tensiometer measures soil tension.

SOIL MOISTURE SENSORS:

Methods and equipment used for irrigation scheduling* ***Chart modified from Colorado State University Extension Bulletin no. 4.708 by I. Broner, Agricultural Engineer and Associate Professor.***

Method	Measured Parameter	Equipment Needed	Irrigation Criterion	Advantages	Disadvantages
Hand feel and soil appearance	Soil moisture content by feel	Hand probe or shovel	Soil moisture content	Easy; simple; experience im- proves accuracy	Low accuracy; field work to take samples
Gravimetric soil moisture sample	Soil moisture content by weight of sample before and after drying	Auger, containers and oven	Soil moisture content	High accuracy	Labor intensive; time delay between sampling and results
Tensiometers	Soil moisture tension	Tensiometer tubes and vacuum gauge	Soil moisture tension	Good accuracy; instantaneous reading of soil moisture tension	Labor to install and make field readings; needs maintenance, especially with prolonged high tension
Electrical resistance blocks	Electrical resistance of soil moisture	Resistance blocks with AC bridge meter (gypsum blocks or granular matrix sensors, such as water- marks)	Soil moisture tension	Fair to good accuracy; instantaneous reading; works over large range of tensions; can be used for remote reading or data logging	Labor to install and make field readings; needs some maintenance; affected by soil salinity; not sensitive at low tensions (near field capacity)
Water budget approach (checkbook method)	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall; model to predict Et	Weather station or available weather data	Estimation of moisture content	No field work required; flexible; can forecast irrigation needs; can be used to schedule multiple fields	Needs calibration and periodic adjustments, since it is only an estimate; calculations can be cumbersome without a computer
Modified atmometer	Reference Et (substitutes for other weather measurements used to calculate Et)	Atmometer gauge (Et gauge)	Estimate of moisture con- tent	Easy to use; gives direct reading of reference Et	Needs calibration; it is only an estimate

Crop Symptoms of Water Stress

Using the plant as an indicator is difficult because once symptoms appear, the plant has usually already experienced a reduction in growth or damage to plant tissues, and economic damage has been done to the crop. However, a few methods have been developed to indicate the onset of plant water stress.

Although these methods may show that the plant needs water, they give no indication of how much. It is very important to understand that they probably don't indicate the onset of water stress early enough for irrigation scheduling purposes.

- Visual Symptoms. These include plant color, plant wilting, leaf growth, fruit growth, as well as stem or trunk growth
- Leaf Temperature. Leaf temperature tends to be higher for a stressed plant than for an unstressed plant. Temperature can be quickly measured using an infrared thermometer
- Leaf Reflectance. Water-stressed leaves reflect less infrared light than the leaves of well-watered plants. Aerial infrared photography has been used to detect water stress in this way
- Instruments. Instruments can measure stomatal (leaf pore) conductance and transpiration, which tends to decrease as water stress becomes more severe

Irrigation Scheduling

Using Evapotranspiration Data: The Checkbook Method

The water balance or "checkbook" method can be used to schedule irrigation using evapotranspiration and precipitation data. The method is inexpensive, simple and relatively accurate. It assumes:

- soil water is a reservoir of available water
- field capacity is reached when the reservoir is full (soil is saturated)
- crop water use (evapotranspiration) takes water out of the reservoir
- rainfall and irrigation add water to the reserve

The checkbook method estimates soil water balance based on water loss from evapotranspiration and water gain from rainfall and irrigation. When the soil water balance for the crop root zone reaches a predetermined level, the grower should begin irrigating. The grower needs to obtain daily evapotranspiration data from a reliable source such as the National Weather Service. Atmometer gauges are also available for placement on the farm and provide a good estimate of the evapotranspiration for certain crops. The grower also needs to track daily precipitation data and keep a record of irrigation applications.

The grower first must determine the maximum amount of crop-available soil water, which is the field capacity of the soil in the root zone of the crop. The allowable soil water depletion is then determined for the crop based on grower experience, literature, or the rule-of-thumb of 50 percent of the total crop-available soil water. This allowable depletion level is known as the irrigation trigger point. During prolonged dry periods, it is often not possible to apply water to crops quickly enough to stay above the irrigation trigger point. To account for this, growers may need to begin irrigating some fields before reaching the irrigation point.

The checkbook water balance method is best begun after a soil saturating rain that brings root zone soils to field capacity. The soil water balance is then updated daily by subtracting the current water loss values (evapotranspiration) and adding current rain- fall values and current irrigation values to the previous day's soil water balance.

Important Note: When using the checkbook method over several days or weeks, the accuracy of the soil water balance method should be compared to direct measurements such as the hand feel method or a few well-placed reference sensors.

Scheduling By Computer
Remote irrigation application schedulers are available for desktop and mobile applications. Additionally, irrigation worksheets can be easily built using a computer spreadsheet program. Cornell University's Climate Smart Farming Program offers a water deficit calculator. The Natural Resources Conservation Service offers a variety of planning tools for water management.

Field Irrigation, Luminosity Photo

Water balance - irrigation scheduling worksheet example

(See USDA - NRCS Irrigation Guide Part 652, Chapter 9, Figure 9-9)

Grower: Brown	Field ID: P14	Crop: Potato - Superior
Planting date: 5/3/2003	Full cover date: 7/13	Harvest date: 8/28
Soil water holding capacity (in/ft): 1.92"		Rooting depth: 18" (F.C.=2.88")
Management allowable depletion: 40%		Minimum soil-water content: 1.73"

Date	Daily crop ET (in)	Forecast crop ET (in)	Cum total ET (in)	Rain (in)	Irrigation applied (in)	Cum total irrigation (in)	Allowed depletion balance (in)	Soil water content (in)	Predicted irrigation date
6/28									
6/29	0.15	0.15	0.15	1.10	0.00	0.00	1.15	2.88	F.C.
6/30	0.15	0.15	0.30	0.00	0.00	0.00	1.00	2.73	7/6
7/1	0.12	0.15	0.42	0.00	0.00	0.00	0.88	2.61	7/6
7/2	0.21	0.20	0.63	0.00	0.00	0.00	0.67	2.40	7/6
7/3	0.20	0.20	0.83	0.00	0.00	0.00	0.47	2.20	7/6
7/4	0.18	0.18	1.01	0.33	0.00	0.00	0.62	2.35	7/7
7/5	0.17	0.18	1.18	0.00	0.00	0.00	0.45	2.18	7/7
7/6	0.22	0.20	1.40	0.00	0.00	0.00	0.23	1.96	7/7
7/7	0.21	0.20	1.61	0.00	0.00	0.00	0.02	1.75	7/8
7/8	0.21	0.20	1.82	0.00	0.50	0.50	0.31	2.04	7/10
7/9	0.23	0.20	2.05	0.00	0.00	0.50	0.08	1.81	7/10
7/10	0.25	0.20	2.30	0.00	0.75	1.25	0.58	2.31	7/13
7/11	0.22	0.20	2.52	0.00	0.00	1.25	0.36	2.09	7/13
7/12	0.19	0.20	2.71	0.00	0.00	1.25	0.17	1.90	7/13
7/13	0.15	0.15	2.86	0.00	0.00	1.25	0.02	1.75	7/14
7/14									

6. Irrigation Water Source Permitting in Maine

Regulatory information in this chapter is current as of May 2024, but may be subject to revision. Readers are advised to contact the regulatory agencies directly for any updates.

Grower Standing in Field, Gregory Hayes

Introduction

The State of Maine and the Federal government have a responsibility to protect the quality and quantity of our natural resources. As such, there are many different agencies involved in setting standards and granting permission to alter a wetland or water body for irrigation water source development.

The Maine Department of Environmental Protection (DEP) regulates projects in organized townships in Maine. The Land Use Planning Commission (LUPC) regulates projects conducted in unorganized and deorganized areas of Maine, including townships, plantations, and some small towns. Such projects may be under Federal jurisdiction, and the agency responsible for this oversight is the United States Army Corp of Engineers (USACE). Together with the United States Environmental Protection Agency (EPA), the USACE administers natural resource permitting programs for the Federal government. This guide will describe a step-by-step process for growers to ensure that there are no surprises along the road to permitting an irrigation water source.

The USDA Natural Resources Conservation Service (NRCS) and the Maine Department of Agriculture, Conservation and Forestry may be able to assist during many steps of this process. They have the technical resources to produce dam designs and whole farm water use plans. The NRCS would be able to conduct wetland delineations if they are required. However, help from NRCS is dependent on local workloads and priorities. Also, the Farm Bill requires that, if any significant assistance is given to a farmer for a project that alters wetlands, they must prepare a mitigation plan. The USACE may also require a mitigation plan. In that case the USACE requirements are used for USDA requirements. Eligibility for USDA programs may also be contingent upon adoption and adherence to mitigation requirements. The Maine DACF and NRCS have cost share programs for new water sources and can provide assistance with water budgets and management plans.

6.1 Abbreviations

- SWCD–Soil and Water Conservation District
- NRCS–Natural Resources Conservation Service
- DACF- Maine Department of Agriculture, Conservation and Forestry
- USDA–U.S. Department of Agriculture
- DEP–Maine Department of Environmental Protection
- LUPC–Maine Land Use Planning Commission
- EPA–U.S. Environmental Protection Agency
- USACE–Army Corp of Engineers, Department of the Army
- DIF&W–Maine Department of Inland Fisheries and Wildlife
- ASC–Maine Atlantic Salmon Commission
- USFWS–U.S. Fish & Wildlife Service
- DMR–Maine Department of Marine Resources
- NMFS–National Marine Fisheries Service

6.2 Step 1: Management Plan

Well, Constructed Pond, and Direct Withdrawal
Most of the elements for any permit will be included in a well-written water use plan. The plan should include an analysis of alternatives, especially if the project will change a wetland in any way. This includes well installment. State and federal agencies are very concerned that all projects avoid, minimize and mitigate affected water bodies, including wetlands. Examples of alternative water sources are included in the Whole Farm Irrigation Water Use Template in the Appendix.

6.3 Step 2: Site Visit

Well, Constructed Pond, Direct Withdrawal
It is important to discuss any project with the people that will review the permit application. This is best done through a site visit with all state and federal agencies that have jurisdiction over the site location and project type. It is helpful to have someone from each agency present at the site visit, so that they can discuss their requirements and suggestions with the grower and with each other. Often, these officials are willing to work with the grower and the other agencies to accommodate special needs as necessitated by each project. Agency personnel prefer to have the Whole Farm Irrigation Water Use Plan before the site visit, so they can familiarize themselves with the proposed project. Provide this plan to each of the agencies invited to the site visit at least a week before the visit.

At the site visit the farmer should be given, or notified about, each form or process the individual agencies will require to apply for their permit. Some agencies such as the Maine Department of Inland Fisheries and Wildlife (DIFW) do not require a permit but do require that certain conditions be met to facilitate the permitting process of other agencies. It is important to be prepared for this meeting and to ask questions and take notes. If the project will be affecting wetlands, have documentation to show alternatives that were considered to avoid, minimize, and mitigate impacts. If mitigation is necessary, offsite wetland creation / restoration / preservation may be required to compensate for lost functions and/or values of the original wetland area. Agency personnel prefer to see a water use plan before a site visit.

The U.S. Army Corps of Engineers defines a wetland as an area that is inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.An upland location is simply one that is not a wetland by the above definition.

6.4 Step 3: Permits

LUPC Jurisdiction

Maps and data are available online here:
https://www.maine.gov/dacf/lupc/plans_maps_data/digital_maps_data.html#viewer

Well, Constructed Pond, Direct Withdrawal
LUPC
Activities and uses in the LUPC service area are regulated based on the zoning of the parcel where the activity is planned to occur. Consult the LUPC's Zoning and Parcel Viewer (https://www.maine.gov/dacf/lupc/plans_maps_data/digital_maps_data.html#viewer) and specific zoning map PDFs, which are available on the website under the Zoning Maps tab or from the regional LUPC office in your area.
LUPC requires a permit for any activity that will drain, drench, or alter a water table. This includes direct withdrawals from streams, irrigation wells (considered non-residential wells), constructed ponds of certain size, location, and condition (see details in the ponds section of this document), the establishment of a pumping site, and the construction of any access roads that may be required. Test wells and laying irrigation pipes do not require a permit.
Below are attachments needed for some irrigation-related permit applications. This is not an all-inclusive list, but it demonstrates the type of information necessary in a complete permit application for LUPC.

1) Location map: name and location, size, and classification of waterbody
2) Right, title, or interest for the site and Corporate Good Standing, if applicable
3) Alternatives analysis: *This may be included in the irrigation plan for the farm.*
4) Farm irrigation plan with target crop acreage, irrigation season, gallons to be used, pumping rate, etc.

5) Site plans and erosion & sedimentation control plans: *if site improvements are proposed*
6) Pump location: include containment and spill plan
7) Access roads: *if new roads are to be constructed*
8) Engineered plans for dams, including outlet/spillway and outlet flow rate
9) Hydrogeologic analysis- for large-scale groundwater withdrawals, pump test results, well logs, hydrographs, precipitation data (if available), test well locations
10) For Direct Withdrawals- evidence that the MDEP's Chapter 587, In-Stream Flow Rule will be met
11) Monitoring Plan: *if surface waters or wetlands, would be significantly impacted,* see below
12) Wetland Supplement- Delineation of wetlands to be altered, LUPC protection subdistrict mapped wetlands, mitigation plan if an area of P-WL2 or P-WL3 wetland larger than 20,000 square feet, or P-WL1 wetland larger than 500 square feet, would be altered.
13) Habitat assessment in consultation MDIFW and MNAP (if sensitive areas such as salmon or other significant fisheries, deer yards, vernal pools, waterfowl and wading bird habitat, or S1/S2 natural plant communities are present)
14) Application Fee

LUPC's staff is tasked with balancing protecting the environment and accommodating the needs of landowners. They have minimal staff, considering the large territory they cover. Certain site-specific data recording requirements may be a permit requirement, aside from the normal water use reporting, which is a requirement for all irrigation permits granted by LUPC. (See more about water use reporting in the Regulations section of this guide.)
Note: For projects involving discharge of water into another water body that would change the receiving water body's classification, a DEP discharge license may be required.

LUPC staff are sensitive to the needs of the environment and try their best to accommodate the needs of their customers. They have minimal staff, considering the territory they cover, so this can mean that at a specific site certain data recording requirements may be a permit requirement, aside from the nor- mal Water Use Reporting, which is a requirement for all irrigation permits granted by LUPC. (See more about Water Use Reporting in the Regulations section of this guide).

DEP (Organized Towns) Jurisdiction

The DEP implements several laws and regulations that may be applicable, or of interest, for certain agricultural irrigation projects. They are summarized below.

Direct Withdrawal - Chapter 587 - In-Stream Flows and Lake and Pond Water Levels
Chapter 587 (the rule) became effective August 24, 2007 and was promulgated in accordance with a statutory directive under 38 M.R.S., §470-H. The rule establishes river and stream flows, and lake and pond water levels, to protect natural aquatic life and other designated uses in Maine's surface waters. The rule specifies the water levels and flows that must exist, and be maintained, for these water bodies to be used as a source of irrigation.

Water may be withdrawn from surface waters for agricultural irrigation under the following conditions:

1. When water levels or flows are higher than those specified in the rule for a water body type or class, irrigation water may be withdrawn without approval. This is self-implementing based on the water levels and flows and no permit is required. (During times of moderate to exceptional drought, water flows in streams and rivers will likely be lower than the required levels and may not be used for irrigation without site specific DEP approval as noted in #2 below.)

2. When the water levels or flows are lower than those specified in the rule for a water body type or class, irrigation water may only be withdrawn with site-specific written DEP approval. Site-specific approvals are based on information provided by the applicant and collected by the DEP. The process requires a 30-day public comment period and consultation with other natural resource agencies such as DIFW and DACF. To issue a site-specific approval, the DEP must be able to establish site specific water levels or flows that would enable a finding that all water quality standards will be attained. (During times of moderate to exceptional drought, water flows in many streams and rivers may not be adequate to allow for issuance of a site-specific approval.)

3. In addition, for rivers or streams, DEP interprets Maine Law at 38 M.R.S., Sec. 470-B to allow withdrawal of 20,000 gallons per day, or withdrawal of one percent of the estimated low flow volume that occurs for 7 days in 10 years based on historical flows, and for lakes and ponds withdrawal of volumes in gallons per week based on acreage of the waterbody, as specified in the law.

There is no fee for water withdrawals under the rule. Additional information on the rule, along with an application form to request a site-specific level or flow are available on the DEP's website here: https://www.maine.gov/dep/water/swup/

Creation of Agricultural Irrigation Ponds

The creation of an agricultural irrigation pond is regulated by standards established in law at 38 M.R.S. § 480-Y. The law stipulates that a general permit is required for the alteration of a freshwater, nontidal stream to construct an agricultural irrigation pond. If the provisions of this section are met, an individual permit is not required.

The law specifies the following eligibility requirements: the farm must have an irrigation management plan, the DEP must have assessed the affected area as having no significant habitat for fish and wildlife, the pond may not be located in a wetland containing endangered or threatened plant species, a site assessment must be conducted by the DEP prior to the submission of an application, the pond may not be located in a river, stream or brook if the DEP determines at the site assessment that there is a practicable alternative water supply that would be less damaging to the environment. The law also specifies application requirements and the following approval process:

"The department shall notify the applicant in writing within 30 days of acceptance for processing if the Department determines that the requirements of this section have not been met. This notification must specifically cite the requirements of this section that have not been met. If the Department has not notified the applicant under this section within the specified time period, a general permit is deemed to have been granted."

The current total one-time fee for creation of an agricultural irrigation pond can be found here: https://www.maine.gov/dep/feeschedule.pdf
Additional information on agricultural irrigation ponds is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/ip-irrig.htm

Natural Resources Protection Act (NRPA)
Certain irrigation projects, depending on their design and implementation may require permitting under the NRPA. The NRPA, established in law at 38 M.R.S. §§ 480-A – 480-JJ, became effective on August 4, 1988. Permits are required for certain activities that occur in, on, or over any protected natural resource area or on land adjacent to any great pond, river, stream or brook, coastal wetland and some freshwater wetlands. Activities that may require a NRPA permit include: dredging, bulldozing, removing or displacing soil, sand, vegetation or other materials; draining, ditching or dewatering; permanent structures (new, repaired, altered); and filling. Additional information on the NRPA is available on the DEP's website here:
https://www.maine.gov/dep/land/nrpa/index.html

Installation of Agricultural Irrigation Wells
Installation of "significant groundwater wells" are a regulated activity under the Natural Resource Protection Act. However, wells for agricultural use or storage are specifically exempted from the definition of "significant groundwater well" and therefor are not regulated by the DEP.

USACE
The Army Corp of Engineers does not regulate surface or groundwater withdrawals.

NOTE: If a well is to feed an agricultural pond it is necessary to decide whether the pond is to be located in a wetland or upland situation. A pond created in an upland situation will be easiest to get approved, but it is often not feasible. Refer to the next section on creating a pond for more details.

Use a DEP Permit-By- Rule (PBR) notification form for wells to be created between 25 and 75 feet from the high water mark of a water body or open-water wetland.

Constructed Pond
When proposing a pond, two of the major costs can be minimized. Engineering and mitigation can be the most prohibitive costs when developing an irrigation water source. When preparing a Farm Irrigation Water Management Plan, have some simple, preliminary engineering completed. This is all that is needed for the USACE permit. Either at the site visit or after submitting the paperwork the USACE will indicate what sort of mitigation is required, if any. At that time a

decision can be made whether the mitigation will be prohibitive or not. Final engineering can be completed once a decision is made to proceed with the project.

Note: In the Southern and Downeast Regions it is necessary to work with the DMR to ensure passage for migratory fish if an impoundment is part of the proposed project. Migratory fish include alewives, shad, salmon, and sturgeon. Likewise, in the Northern and Western Regions it will be necessary to consult with the DIFW to ensure the passage of fish over dams.

LUPC

Activities and uses in LUPC's service area are regulated based on the zoning of the parcel where the activity is planned to occur. Consult the LUPC's Zoning and Parcel Viewer (https://www.maine.gov/dacf/lupc/plans_maps_data/digital_maps_data.html#viewer), and specific zoning map PDFs that are available on the website under the Zoning Maps tab or from the regional LUPC office in your area.

A permit may be needed to construct a dug pond or impoundment subject to the zoning standards of the project area. The application has many required submissions, so it should be read thoroughly to ensure all necessary aspects are covered. A base fee of $200.00 will be assessed for submission of this application, with the potential for additional activity-specific per-square-foot fees. Please reach out to regional staff early to discuss fees. The Executive Director may reduce fees at their discretion. A fee is charged each time an amendment needs to be made to an approved application.

If the activity involves a wetland in LUPC jurisdiction, a LUPC Wetland Supplement Form must be completed.

Constructed Ponds require a LUPC permit if any of the following apply:

- fed or drained by a stream
- located within a P-WL1 wetland
- larger than 4,300 square feet within a P-WL2, P-WL3, P-GP or P-SL Sub-district
- larger than 1 acre within a M-GN Sub-district

As noted under the Well section, LUPC requires a permit for development, including activities that will alter the water table. This includes direct withdrawals from streams, irrigation wells (also considered a non-residential well), constructed ponds of certain size and condition, the establishment of a pumping site and the construction of any access roads that may be required. In the M-GN Subdistrict, there is a use listing that allows for farm ponds if not fed or drained by a stream. Test wells and laying irrigation pipes do not require a permit.

See the Well section for attachments to a permit that may be necessary. Also, see the LUPC water use reporting requirements under the Regulations section.

Note: For projects involving discharge of water into another water body that could change the receiving water body's classification, a DEP discharge license may be required.

DEP (Organized Towns)

Creation of Agricultural Irrigation Ponds

The creation of an agricultural irrigation pond is regulated by standards established in law at 38 M.R.S. § 480-Y. The law stipulates that a general permit is required for the alteration of a freshwater, nontidal stream to construct an agricultural irrigation pond. If the provisions of this section are met, an individual permit is not required.

The law specifies the following eligibility requirements: the farm must have an irrigation management plan, the DEP must have assessed the affected area as having no significant habitat for fish and wildlife, the pond may not be located in a wetland containing endangered or threatened plant species, a site assessment must be conducted by the DEP prior to the submission of an application, the pond may not be located in a river, stream or brook if the DEP determines at the site assessment that there is a practicable alternative water supply that would be less damaging to the environment. The law also specifies application requirements and the following approval process:

"The department shall notify the applicant in writing within 30 days of acceptance for processing if the Department determines that the requirements of this section have not been met. This notification must specifically cite the requirements of this section that have not been met. If the Department has not notified the applicant under this section within the specified time period, a general permit is deemed to have been granted."

The current total one-time fee for creation of an agricultural irrigation pond can be found here: https://www.maine.gov/dep/feeschedule.pdf
Additional information on agricultural irrigation ponds is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/ip-irrig.htm

Natural Resources Protection Act (NRPA)
Certain irrigation projects, depending on their design and implementation may require permitting under the NRPA. The NRPA, established in law at 38 M.R.S. §§ 480-A – 480-JJ, became effective on August 4, 1988. Permits are required for certain activities that occur in, on, or over any protected natural resource area or on land adjacent to any great pond, river, stream or brook, coastal wetland, and some freshwater wetlands. Activities that may require a NRPA permit include dredging, bulldozing, removing or displacing soil, sand, vegetation, or other materials; draining, ditching or dewatering; permanent structures (new, repaired, altered); and filling.
Additional information on the NRPA is available on the DEP's website here: https://www.maine.gov/dep/land/nrpa/index.html

USACE
The U.S. Army Corp of Engineers regulates the deposit of fill or any other material into the waters of the United States and therefore has jurisdiction pertaining to impoundments where irrigation water source permitting is concerned.

Agricultural activities are given special consideration under USACE rules. Accordingly, any activity in a wetland need NOT have a permit UNLESS the activity results in a change of use of the water body, impairs the flow or circulation of water, or reduces the reach of the water body. Therefore, wetland ponds are exempt from permitting procedures unless Aquatic Base Flow standards are not maintained, as this would "alter the flow or circulation," as limited above.

The Aquatic Base Flow standards in each region are different. The Department of Inland Fisheries and Wildlife has a certain standard, where other agencies may have another. In Aroostook County during 2004 there remains a multi-year initiative to establish a Low-Flow policy by studying stream flows over several seasons. The DEP is currently developing Low-Flow standards for Maine as mandated by recent state legislation.

All other projects likely fall within their purview, and it would be helpful to review their document called "Are You Planning Work in a Waterway or Wetland?"

Primarily the USACE is interested in avoiding any impacts on wetlands. Like the State, their philosophy is "no net loss" of wetland. If this cannot be done, all efforts are made to mitigate whatever losses do occur. If it is necessary to mitigate (as will often be the case with the USACE) it will be necessary to de- lineate the wetland, or survey it. Linked here is the USACE manual they use to delineate a wetland and a USACE checklist they follow for reviewing a mitigation plan presented by an applicant.

Mitigation of a wetland can occur in one of four ways. The USACE could require the creation of new wetlands where they don't already occur (which will require replacement of more than the original wetland lost due to the project), restoration of ailing wetlands (which may or may not involve more wetland than was lost by the project), enhancement of an existing wetland (which will be a 1:1 ratio of lost to enhanced wetland) or, on rare occasions, the USACE may require as a prerequisite to being granted a permit that a wetland is protected or maintained by acquiring land adjacent to a wetland that will ensure the wetland health into perpetuity, or another similar method of protection.

The definition of mitigation involves:

1) **Avoiding the impact altogether by not taking a certain action or parts of an action.**
2) **Minimizing impact by limiting the degree or magnitude of the action and its implementation.**
3) **Rectifying the impact by repairing, rehabilitating, or restoring the impacted environment.**
4) **Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.**
5) **Compensating for the impact by replacing or providing substitute resources or environments.**

The USACE will require coordination with natural resource agencies as dictated by the location of the project. Applicants may be required to describe and identify potential impacts to Essential Fish Habitat (EFH) based upon the location of the project, the activity proposed, and the species present. Conservation recommendations made by National Marine Fisheries Service (NMFS) or the Maine Department of Inland Fisheries and Wildlife (DIFW) will normally be included as a permit requirement by the USACE. Information on the location of EFH can be obtained from the NMFS regulations (50 CFR Part 600) and on the NMFS web site.

The EFH designation for Atlantic salmon includes all aquatic habitats in the watershed of the following rivers and streams, including all tributaries to the extent that they are currently or were historically accessible for salmon migration: St. Croix River, Pleasant River, Union River, Boyden River, Narraguagus River, Ducktrap River, Dennys River, Tunk Stream, Sheepscot River, Hobart Stream, Patten Stream, Kennebec River, Aroostook River, Orland River, Androscoggin River, East Machias River, Penobscot River, Presumpscot River, Machias River, Passagassawaukeag River, and the Saco River.

The USACE considers the LUPC or DEP application as their application as well. Projects approved by the USACE will also require an historical value evaluation and letter of approval. In most cases a description of the site will be sufficient for an historical/cultural appraisal to be made, but in other cases a staff person will visit the site to make an evaluation. The Maine Historic Preservation Commission is listed under the Contact Information section.

A USACE permit will be issued for life, but the project must be built within five years of the permit's issuance or another application will need to be submitted. The USACE considers either the LUPC or DEP application as their application as well. Additional information regarding their requirements is available at USACE web site.

Direct Withdrawal

LUPC

Activities and uses in the LUPC service area are regulated based on the zoning of the parcel where the activity is planned to occur. Consult the LUPC's Zoning and Parcel Viewer (https://www.maine.gov/dacf/lupc/plans_maps_data/digital_maps_data.html#viewer), and specific zoning map PDFs that are available on the website under the Zoning Maps tab or from the regional LUPC office in your area.

LUPC requires a permit to make water withdrawals. The application consists of a shoreline alteration application (Shoreland Alteration Application Form maine.gov) with some additional exhibits that staff can outline in pre-application discussions. A base fee of $200.00 will be assessed for submission of this application, with the potential for activity-specific per square foot fees. Please reach out to regional staff early to discuss fees. The Executive Director may reduce fees at their discretion. A fee is charged each time an amendment needs to be made to an approved application.

If the activity involves a wetland in LUPC service area it will be necessary to fill out a Wetland Supplement Form.

As noted under the Well section, LUPC requires a permit for development, including any activity that will alter the water table. This includes direct withdrawals from streams, the establishment of a pumping site, and the construction of any access roads that may be required. Laying irrigation pipes does not require a permit.

See the Well section for attachments to a permit that may be necessary. Also, see the LUPC water use reporting requirements under the Regulations section.

DEP

Direct Withdrawal - Chapter 587 - In-Stream Flows and Lake and Pond Water Levels

Chapter 587 (the rule) became effective August 24, 2007 and was promulgated in accordance with a statutory directive under 38 M.R.S., §470-H. The rule establishes river and stream flows, and lake and pond water levels, to protect natural aquatic life and other designated uses in Maine's surface waters. The rule specifies the water levels and flows that must exist, and be maintained, for these water bodies to be used as a source of irrigation.

Water may be withdrawn from surface waters for agricultural irrigation under the following conditions:

1. When water levels or flows are higher than those specified in the rule for a water body type or class, irrigation water may be withdrawn without approval. This is self-implementing based on the water levels and flows and no permit is required. (During times of moderate to exceptional drought, water flows in streams and rivers will likely be lower than the required levels and may not be used for irrigation without site specific DEP approval as noted in #2 below.)

2. When the water levels or flows are lower than those specified in the rule for a water body type or class, irrigation water may only be withdrawn with site-specific written DEP approval. Site-specific approvals are based on information provided by the applicant and collected by the DEP. The process requires a 30-day public comment period and consultation with other natural resource agencies such as Inland Fisheries and Wildlife and Agriculture, Conservation and Forestry. To issue a site-specific approval, the DEP must be able to establish site specific water levels or flows that would enable a finding that all water quality standards will be attained. (During times of moderate to exceptional drought, water flows in many streams and rivers may not be adequate to allow for issuance of a site-specific approval.)

There is no fee for water withdrawals under the rule. Additional information on the rule, along with an application form to request a site-specific level or flow are available on the DEP's website here: https://www.maine.gov/dep/water/swup/

Natural Resources Protection Act (NRPA)

Certain irrigation projects, depending on their design and implementation may require permitting under the NRPA. The NRPA, established in law at 38 M.R.S. §§ 480-A – 480-JJ, became effective on August 4, 1988. Permits are required for certain activities that occur in, on, or over any protected natural resource area or on land adjacent to any great pond, river, stream or brook, coastal wetland and some freshwater wetlands. Activities that may require a NRPA permit include:

dredging, bulldozing, removing or displacing soil, sand, vegetation or other materials; draining, ditching or dewatering; permanent structures (new, repaired, altered); and filling. Additional information on the NRPA is available on the DEP's website here:
www.maine.gov/dep/land/nrpa/index.html

USACE
The Army Corp of Engineers does not regulate surface or groundwater withdrawals.

6.5 Other Regulations

Constructed Pond
Eligibility for any USDA Farm Service Agency (FSA), Rural Development (RD) or Natural Resources Conservation Service (NRCS)) program hinges on compliance with the Swampbuster provisions of the Farm Bill. Even if the applicant is not participating in any programs administered by the USDA, this process is necessary for future participation these programs. Forms AD-1026 and CPA-38 will need to be completed.

Pond, Sikes Photos

Regulations: LUPC Monitoring Requirements
Data and Annual Reporting for LUPC Irrigation Permits
The following types of data are required for certain permit applications, for continued monitoring after the permit is issued, and for annual reporting:

All projects
- Water Usage: Monitoring is required for all types of irrigation permits.
- Record volumes withdrawn by day, month, and year.
- Record pumping rates (generally estimated based upon number and type of sprinklers used).

Large-scale surface water withdrawals
- Pond/Lake Levels & Stream/River Flows: Monitoring of stage and/or flow may be required for certain direct surface water withdrawals.
- Record weekly the background stage or flow of ponds, lakes, streams, and rivers during irrigation, and one month preceding and following the irrigation season.
- Record daily when water withdrawals are occurring.
- Determine stage-discharge relationships for flow monitoring sites.
- Monitoring of surface water bodies may be required for irrigation wells if ground water withdrawals could potentially affect adjacent surface water.

Large-scale groundwater withdrawals
- Ground Water Levels: Monitoring may be required for large-scale (non- residential) well permits.
- Record background levels one month preceding and one month following the irrigation season.
- Record levels weekly during the irrigation season at monitoring wells established during pump testing.
- As noted in above, it may be necessary to record levels of adjacent surface water bodies.

Wetland monitoring
- Monitoring may be required on a case-by-case basis if the permit review determines that a ground or surface water withdrawal could potentially affect a wetland.
- Piezometers are used to monitor water levels in the wetland, done weekly during the irrigation season and one month before and after the season.
- Vegetation plots must be monitored once during the growing season.

Reporting:
- Data must be available to LUPC staff upon request during the irrigation season
- Mid-season reports may be required in some cases.
- An annual summary may be required, generally by December 31 of the calendar year.

6.6 Contacts

Permit Agencies

DEP
Brian Kavanah, *Director of Water Quality*
Phone: (207 530-0293
E-mail: Audie.T.Arbo@maine.gov

Robert Wood, *Director of Land Resources*
Phone: (207) 855-8361
E-mail: Robert.Wood@maine.gov

Dawn Hallowell, *Land Licensing Division Director*
Phone: (207) 557-2624
E-mail: Robert.Wood@maine.gov

DEP Regional Offices

LUPC
Audie T. Arbo, *Permitting and Compliance Manager*
Phone: (207) 557-2023
E-mail: Audie.T.Arbo@maine.gov

LUPC Regional Offices

USACE
U.S. Army Corps of Engineers Maine Project Office
442 Civic Center Drive, Suite 350
Augusta, Maine 04330
Phone: (207) 623-8367
Email: mailto:cenae-r-me@usace.army.mil

Technical Assistance

NRCS
State Office- https://www.nrcs.usda.gov/contact/state-office-contacts/maine-state-office
Field Offices- https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/maine

Soil & Water Conservation Districts
SWCD Offices- https://www.maine.gov/dacf/about/commissioners/soil_water/index.shtml

7. Introduction to Irrigation Costs and Returns

Variability in crop yield due to weather events can impact profitability. The use of irrigation for agricultural crops has different implications depending on the amount of rainfall needed by the crop and the average annual rainfall of the location. In temper- ate regions like Maine, where in some years there is enough rainfall to meet crop needs, the analysis of the costs and benefits depends upon usage since it is used to supplement crop needs when rainfall is insufficient. The range of use for supplemental irrigation can be from "not at all" in wet years, to "frequently" in dry years and, as such, the economic costs and returns of an irrigation system are highly variable from year to year.

Annual irrigation costs are uncertain due to the unpredictability of rainfall and the demand for irrigation water. This source of uncertainty largely determines the annual cost of irrigation. During the production season, annual operating costs will accumulate depending upon the labor intensity of the system, the number of irrigation sets per season, fuel and oil requirements, maintenance, as well as financing charges. One of the most important problems facing decision makers is the ordering of alternative investment decisions with different risky outcomes to determine which option most reduces operator exposure to production risk.

This section describes costs and returns to irrigation systems, summarizing the findings in two studies on irrigation in Maine. One was conducted for wild blueberries and a second for potatoes grown in Aroostook County. **Note that these analyses were conducted in 2004 and have not been updated to reflect current prices. Contact the University of Maine Cooperative Extension or the Maine Potato Board for more information on irrigation cost/benefit analysis.**

To derive estimates of cost and returns to irrigation systems, a three-step procedure should be used. First, a prototypical enterprise budget needs to be developed to capture the economic costs associated with irrigation. Second, variable weather and eco- nomic factors associated with irrigation investment and annual usage need to be identified. Third, after identifying the elements affecting revenues and costs, the budgets must be repeated with varying the rainfall amounts and subsequent number of irrigations necessary per season.

To quantify the tradeoffs between initial investment and annual operating expense, different irrigation systems must be evaluated. For potatoes, moveable large gun systems, hose reel traveler systems, and center pivot systems are practical systems to evaluate, while a handline moveable large gun system, a large gun attached to a hose reel system, a handline moveable small sprinkler system, and a permanent set small sprinkler system are the most feasible alternatives for wild blueberries. Costs for each system are demonstrated in this chapter for three field sizes. The investment costs of each system are first calculated. These costs are then depreciated over the life of the system. Second, the annual operating costs are calculated at different levels of usage. The approach used to calculate the costs was the same for both crops. The findings for the two crops are presented in separate sections.

7.1 Wild Blueberry Irrigation

Note that these analyses were conducted in 2004 and have not been updated to reflect current prices. Contact the University of Maine Cooperative Extension for more information on irrigation cost/benefit analysis.

In this analysis, each field is assumed to be equally divided between fruit-bearing and non-bearing plants. All systems were designed to minimize rainfall risk on both the fruiting and non-fruiting sides of the field. Due to limited water-holding capacity of many soils in the blueberry-growing region, systems were designed to apply 2/3" of water, twice a week to ensure that the field would receive 1" of water per week net of application losses. In a worst-case scenario, this is equivalent to having the capacity to water the entire field to ensure bud formation on the vegetative half and berry filling on the fruiting half during one week. The base models assume that 12 of these applications will occur on fruit-bearing land (effectively 6" of water per season) and four on non-bearing land (2" of water per season).

Table 1. Irrigation System Characteristics

Irrigation System	Investment Capital Requirement	Frost Protection	Management Input	Labor Requirements	Expandable
Handline Moveable Large Gun	Low	No	Moderate to High	High	Yes 1
Hose Reel Large Gun	Low	No	Low	Low	Yes 1
Handline Small Sprinkler	Medium	Limited	Moderate to High	High	Yes 1
Permanent Set Small Sprinkler	High	Yes	Low	Low	N/A2

Only the permanent set, small sprinkler system can provide complete field protection against frost. The handline small sprinkler system can provide limited protection depending upon how much area can be covered by the equipment. If frost damage is the primary concern of the operator, then only these systems can effectively reduce yield loss due to frost damage.

Cost Analysis Assumptions

All irrigation systems were assumed to be located on level, rectangular fields. The 25-acre field measures approximately 1200' (length) by 900' (width), the 50-acre, 2400' by 900', and the 100-acre, 2400' by 1800'. Water is pumped from a farm pond located 100' from the irrigated field and all systems are assumed to have the same cost to develop the water source. The power unit, sized to meet system peak capacity, and pump are located at the site of the pond. Water is pumped by a diesel power unit from the pond through the main line to the lateral delivery lines and subsequently to the delivery systems.

Ownership Expenses

Total investment costs represent the approximate cost to establish the four different systems described earlier, including water source development, diesel engine, pump, main and lateral delivery lines, sprinkler system, and installation labor. These costs were derived from interviews with irrigation equipment dealers conducted during 2001. Sales tax is not added to the total cost under the assumption that the grower holds a commercial agricultural production sales tax exemption certificate.

Operating Expenses

Operating costs to run and maintain the irrigation systems are calculated in a partial budget format; that is, only costs associated with the operation of the irrigation system are captured. Each of these models assumes that there will be 12 irrigations per season on the land producing fruit and four upon non-bearing acreage. There are four primary components of the operating cost budgets: labor, power, maintenance, and interest charges.

Labor costs accumulate from two different sources: initial set up and end-of-season take-down of the system and variable labor usage per irrigation, excluding managerial time. These per acre coefficients are applied uniformly across the three different acreage examples. A $9.40 hourly wage rate is applied in the calculations. This wage rate is based upon the 2001 Adverse Effect Wage Rate of $8.17 and inflated by 15% to account for meals and other benefits entitled to immigrant workers. Since managerial labor is not included in the calculation, a constant cost-per-acre labor charge is calculated for the four different systems.

Power costs are calculated by determining the number of hours that the pumping unit will operate to apply 8″ of water on bearing land and 2-2/3″ on non-bearing growth. Total pumping time is inflated by 10% to account for flushing, system testing, and mistakes. Total pumping time is then multiplied by hourly fuel-consumption rates of the different diesel motors and then by the per gallon price of diesel fuel ($1.25). This diesel price is based upon sales-tax-free prices from summer 2001. Average fuel costs decline as acreage increases, reflecting economies of size in motor pumping.

Maintenance and upkeep charges are calculated for these systems as a fixed coefficient of initial purchase price. These coefficients represent an average charge that should be incurred over the life of the irrigation component, not one representing a new piece of equipment with little or no maintenance nor an old one with high upkeep costs. Pieces of equipment with moving parts require higher maintenance costs than fittings. Maintenance and upkeep on tubing represents limited unforeseen breakage.

The final component of the operating budget is an interest charge on working capital used during the production season. The interest charge represents the financial cost of a short-term operating loan or the opportunity cost of producer capital used to pay for these expenses before blueberry receipts are received. A short-run nominal interest rate of 8%, inflation adjusted to 4.7%, is applied over a seven-month period, (e.g., April through October) on the balance of labor, fuel, and maintenance charges. This rate is a representative rate provided to producers by the Farm Credit Service for short-term operating loans.

Partial Cost Budgets for Wild Blueberries

Incremental cost budgets are calculated on a per acre basis. The cost budget of the irrigation system is composed of two elements: ownership costs tied to depreciation, interest, tax, and insurance costs, and operating charges distinctly attributable to the irrigation process. These budgets are presented in the following tables for the large gun, hose-reel traveler, handline small sprinkler, and permanent set small sprinkler systems, respectively.

Overall, the hose-reel systems are the least expensive to own and operate, followed by the handline big gun system, and the handline sprinkler system. The permanent set system is the costliest. These illustrative budgets can be used to examine the trade- offs between capital investment and annual operating charges, in particular, tradeoffs between equipment and labor. The largest cost component lies with depreciation and interest on the irrigation equipment. Depreciation and interest accounts for 50% to 63% of total cost in the handline systems, 40% to 62% in the traveler systems, and 75% for the permanent set sprinkler arrangement. The importance of this cost category decreases as field size increases, illustrating economies of field size.

Labor is the second most important cost component. Both handline systems require considerable seasonal labor to move and operate the irrigation systems. Total labor cost is the highest on the handline sprinkler system, followed by the handline big gun system. Permanent set systems have the third highest labor cost due to initial set-up and take-down requirements.

The third most important cost category is linked to fuel costs. Although the permanent set systems require the largest diesel engines for pumping, they run the fewest hours to deliver the required water. As a result, fuel costs are only 2% of the budget. Combined, fuel, labor, and depreciation and interest costs account for about 90% of total irrigation costs.

7.2 Potato Irrigation

Note that these analyses were conducted in 2004 and have not been updated to reflect current prices. Contact the University of Maine Cooperative Extension or the Maine Potato Board for more information on irrigation cost/benefit analysis.

The three technology-alternative irrigation systems used to irrigate potatoes are distinctly different. In general, systems that have a high initial investment cost require less annual labor to operate than low investment cost systems. In addition, the technical operating characteristics of the three systems are different and affect fuel and maintenance requirements. Given the highly variable requirement of irrigation water from year to year, the tradeoff between investment (and hence annual ownership cost) and variable operating costs is important. In years where irrigation is not required, systems with low fixed costs will be preferred to systems with high fixed costs. On the other hand, during years when demand for irrigation water is high, systems with low operating costs per acre-inch of water will be preferred to high operating cost systems.

Ownership Costs

Capital investment costs were determined through interviews with irrigation engineers and equipment dealers familiar with the production conditions of northern Maine. For each system and field size, investment costs were calculated over five cost centers: 1) permitting and water source development; 2) the pumping system; 3) the main line and lateral delivery system; 4) the water application system; and 5) miscellaneous and system-specific costs. Total investment costs were calculated based upon prevailing market conditions in the fall of 2001 and winter of 2002. The total investment cost for each system is calculated based upon representative conditions facing growers in this region, including a water source that is approximately one-half mile from the fields, an elevation change of 125 feet, and a flat fee of $15,000 for permitting and engineering studies on water withdrawal. All remaining components are sized to ensure that one inch of water per week may be applied to the fields.

Overall, this table illustrates the dichotomy between lower cost “flexible” systems and more capital-intensive systems. By comparison, the center pivot irrigation systems are between 46% to 68% more expensive than the lowest cost moveable large gun systems.

Total investment costs are converted to annual ownership costs using annual equivalent worth analysis. This approach converts total investment cost to an annual basis using amortization and other time-value-of-money techniques to derive an economic value for fixed equipment with a lifespan of more than one year. In comparison with the fixed annual cost of supplemental irrigation, annual operating cost is contingent upon the demand for irrigation water.

Operating Expenses

Annual variable costs associated with irrigation include labor to prepare the system for its first usage, the labor required per irrigation set, fuel to operate the pumping system, maintenance and upkeep charges, and financing charges linked to operating expenses accrued during the season.

Labor costs accumulate from two different sources: initial setup and end-of-season take-down of the system, and variable labor usage per irrigation. These per acre coefficients are applied uniformly across the three different acreage examples. A $9.40 hourly wage rate is applied in the calculations. This wage rate is based upon the Maine Adverse Effect Wage Rate of $8.17 and inflated by 15% to account for meals and other benefits entitled to immigrant workers. Alternatively, it can be seen as the benefits premium (Social Security, Unemployment Compensation, Workers Compensation Insurance) attached to attract local workers from non-agricultural employment alter- natives. Since managerial labor is not included in the calculation, a constant cost-per- acre labor charge is calculated for the four different systems.

Power costs are calculated by determining the number of hours that the pumping unit operates to apply the required amount of irrigation water. Total pumping time is inflated by 10% to account for flushing, system testing, and mistakes. Total pumping time is then multiplied by hourly fuel-consumption rates of the different diesel motors and then by a representative per-gallon price of diesel fuel ($1.25). Average fuel costs decline as acreage increases, reflecting economies of size in motor pumping.

Maintenance and upkeep charges are calculated for these systems as a fixed coefficient of initial purchase price. Maintenance and upkeep coefficients are derived from interviews with equipment dealers and referenced against Paterson et al. (1996a; 1996b). These coefficients represent an average charge incurred over the life of the irrigation component, not one representing a new piece of equipment with little or no maintenance nor an old one with high upkeep costs. Pieces of equipment with moving parts require higher maintenance costs than fittings. Maintenance and upkeep on tubing represents limited unforeseen breakage.

The final component of the operating budget is an interest charge on working capital used during the production season. The interest charge represents the financial cost of a short-term operating loan, or the opportunity cost of producer capital used to pay for these expenses before potato receipts are received. A short-run nominal interest rate of 8%, inflation adjusted to 4.7%, is applied over a seven-month period (e.g., April through October) on the balance of labor, fuel, and maintenance charges.

Nearly 90% of potato production in Maine occurs in the northernmost county of the state. As such, this study evaluates the cost of irrigation systems located within this geographical area and in the context of the historical weather patterns in the heart of the growing region. Over the 40-year period from 1959 to 1998, total rainfall during June through August was normally distributed with a mean of 11.8 inches and a variance of 5.8 inches. Nonetheless, the probability of receiving one inch of rainfall per week, to ensure proper crop development, is highly variable. During the early part of the season, this probability drops to less than 20%, and during the critical stages of tuber bulking in August and early September, it is less than 35% (NCDC).

Operating Costs and Benefits Estimation

Uncertainty in cost estimation arises from not knowing with precision how much irrigation water will be required during the season. Since usage is not known with certainty, the underlying cost functions also are not known with certainty. As the annual ownership costs are fixed without respect to usage, this component of total annual cost favors systems with lower investment costs. On the other hand, these lower cost systems have higher variable operating costs per application. The large gun systems require significantly more labor than the hose reel travelers or the center pivot systems. Fuel costs are dependent upon the size of the pumping unit and the number of hours that the system is operated. Maintenance and upkeep charges are related to usage and the investment cost of the systems.

Annual ownership costs are netted from gross expected revenue and total variable costs of production. The problem is subject to the producer constraint that 14 inches of water is needed on the crop over the months of June, July, and August. This amount of crop water can be applied in the form of irrigation water or through rainfall. Water applied through irrigation is a function of the inputs used in irrigation process given the stock of capital and the technical requirements of irrigation technology alternative.

The decision to irrigate is determined by summing the difference between the desired one inch per week and observed rainfall amounts until a cumulative one-inch deficit is achieved. Once the deficit occurs, the field is irrigated to ensure that one inch reach es the crop.

Based upon weather data between 1959 to 1998, total seasonal rainfall is normally dis- tributed with a mean of 11.8 inches, a standard deviation of 2.4 inches, an observed minimum of 7.2 inches and maximum more than 14 inches. Therefore, irrigation requirements range from zero inches to 6.8 inches per season, but average 2.2 inches per year. The decision to irrigate, however, is contingent upon a one-inch deficit to pre- vent infrequent and costly short irrigations. Based upon these characteristics, net returns to irrigated and non-irrigated production are calculated. These results are compared to determine the mean benefit and the risk reduction effects.

Partial Budget Results

Based upon the expected demand for irrigation water, cost budgets for the three systems over three acreages are presented in the following tables. These cost budgets are calculated based upon the expected value of the number of irrigations. Several trends merit discussion. In the annual operating cost category, per-acre power costs decline as acreage increases due to non-linear fuel consumption of larger diesel engines. Maintenance and upkeep charges also decline, reflecting the impact of distributing these costs over a larger acreage.

Ownership costs also decline as acreage increases. Despite higher investment costs as acreage increases, these costs are distributed over a wider irrigated area, thereby decreasing average cost per acre. As tax and insurance charges are based upon the replacement cost of the system, they decrease on a per acre basis when diffused over larger fields.

According to the budget results in the table, the handline large guns are the lowest cost irrigation technology based upon expected irrigation usage. Comparison between the acreage sizes indicates decreasing average cost per acre, or economies of size in irrigation. Doubling acreage from 50 to 100 acres decreases the average total annual cost of irrigation by 27% and 29% for the handline and traveling gun systems but by 43% for the center pivot system. Doubling field size again, from 100 to 200 acres, decreases average total annual cost by 22%, 12% and 28% for the handline large gun, hose reel traveler and center pivot systems, respectively. Overall, this implies that the average annual total cost is nearing its size efficient minimum for the hose reel traveler system, but size economies still exist for the two other systems.

Risk Management Attributes of Irrigation Systems

Given that demand for irrigation water is dependent upon rainfall, the resulting cost estimates will have a variable component mirroring the derived demand for irrigation water. While total cost increases with the amount of irrigation water applied, average cost per acre-inch of water declines. Nonetheless, when this budget is added into the non-irrigated crop production budget, total annual cost of production will be greater under irrigation in all states of nature. Revenue will vary according to total annual rainfall. Revenue variability is decreased under irrigated production, but the expected impact will not always be greater than non-irrigated production, i.e. in years when supplemental irrigation is not required. As a result, the net return to irrigation may not always be positive, especially in years when limited water is applied to the crop.

The median net return per acre to irrigated production is uniformly higher for all irrigation systems applied on 100 or 200 acres, but lower for the center pivot on 50 acres. As a result, two distinct cases occur. In the 100- and 200-acre scenarios, irrigation is an important tool to increase profitability and decrease exposure to weather related pro- duction risk. In the 50-acre cases, median income does not always increase.

Water Development Costs

One of the greatest sources of uncertainty facing potato producers is the cost of developing a water source to meet irrigation demands. The presented scenario is representative of historical water source development costs but largely underestimates current and future costs. Most growers who currently irrigate are in areas where direct water withdrawal from rivers and streams is possible. This technique is currently in disfavor by state and federal authorities with jurisdiction over permitting and will be highly regulated soon.

In the future, in some locations of Maine, irrigators will be required to withdraw water from impoundments or ponds, rather than directly from streams or rivers, thereby increasing the engineering and construction cost. In addition, these ponds may require state permitting and environmental impact assessment. Currently, environmental best practices call for the development of upland ponds rather than impacting wetlands in lowland areas. Both alternatives forbear significantly higher development costs. Upland ponds are extremely expensive because conditions are conducive to infiltration. As such, for these ponds to retain water, an artificial impermeable layer may need to be constructed. On the other hand, if a pond is created in a lowland area, the producer may be required to mitigate any damage to the surrounding lowland or wetland ecology. As such, most experts believe that the $15,000 previously spent to develop a water source will only cover basic environmental engineering and permitting application costs. Construction, non-trivial engineering, and environmental impact assessment, plus wetland mitigation, will increase initial investment and annual ownership expense substantially.

As such, the cost of water source development is a key factor in the decision to invest in irrigation or not. The profitability and risk analysis must be reevaluated when increasing the cost of water development from the base level of $15,000 by $50,000 and $100,000. This cost of water source development can cause a substantial increase in the cost of irrigation but is realistic of recent grower experience. Increasing water development costs do not affect the risks of any of the irrigation options at the 200-acre scale. While the profitability differences decline, irrigation still increases net returns per acre.

On the other hand, the decision to adopt limited irrigation at 50 acres is sensitive to initial water development cost. When costs increase to $65,000, only the handline gun system is risk efficient for a slightly risk adverse producer at the 50-acre scale and the medium investment system for someone who can be characterized as a "highly" risk averse producer. At $115,000 of start-up cost, non-irrigated production dominates all irrigation technologies at 50 acres of coverage. Increasing water development costs has an important impact on the scale level of a producer's decision to adopt irrigation technology.

As such, and holding all other constraints constant, current environmental policy to regulate water development will increase the breakeven scale at which irrigation becomes risk efficient. The current state Department of Agriculture's Water Source Development Cost Share program may be used to achieve welfare improving solutions through cost-sharing water development investment. Under the second scenario, where resource development costs are estimated at $65,000, a 75% cost share would reduce the impact at the 50-acre scale.

Conclusions
Supplemental irrigation has often been described as an "insurance policy." Due to the high investment costs associated with irrigation, size economies are an important com- ponent of feasibility. Current state and federal farm policy is promoting water development cost sharing. This policy will have an important role in inducing the adoption of systems for farmers who are seeking to adopt smaller scale systems. On the other hand, farmers who do not qualify for cost shares will be required to adopt irrigation on a larger scale in order to receive the risk management benefits.

For more information, please see the following publications available from the Maine Agricultural and Forest Experiment Station at the University of Maine:

Dalton, Timothy J., Andrew Files, David Yarborough. 2002, "Investment, Ownership and Operating Costs of Supplemental Irrigation Systems for Maine Wild Blueberries." Maine Agricultural and Forestry Experiment Station Technical Bulletin 183.

Dalton, Timothy J. and David Yarborough. 2004, "The Economics of Supplemental Irrigation on Wild Blueberries: A Stochastic Cost Assessment." Small Fruits Review. 3(1/2): 73-86.

Dalton, Timothy J., Gregory A. Porter and Noah Winslow. 2003, "Profitability and Risk Management Benefits of Supplemental Irrigation on Northern Potatoes." Resource Economics and Policy Staff Paper 515.

Dalton, Timothy J. , G. A. Porter and N. Winslow. 2004, "Risk Management Strategies in Humid Production Regions: A Comparison of Supplemental Irrigation and Crop Insurance." Agricultural and Resource Economics Review. 32(3): 220-232.


Potato Harvest, Jan Antonin Kolar

Appendix

A.1 Abbreviations

ABF	Aquatic Basal Flow
BMP	Best management Practices
CASWCD	Central Aroostook Soil and Water Conservation District
cfsm	Cubic feet per second per square mile of watershed
Et	Evapotranspiration
GPS	Global Positioning System
IF&W	Maine Department of Inland Fisheries and Wildlife
LUPC	Land Use Planning Commission
MASC	Maine Atlantic Salmon Commission
MAWMAC	Maine Agricultural Water Management Advisory Committee
MDACF	Maine Department of Agriculture, Conservation and Forestry
MDEP	Maine Department of Environmental Protection
MGS	Maine Geological Survey
NOAA	National Oceanic and Atmospheric Administration
SPCC	Spill Prevention, Control and Countermeasure
SWCD	Soil and Water Conservation District
USDA	United States Department of Agriculture
USDA-NRCS	United States Department of Agriculture, Natural Resources Conservation Service
USF&W	United States Fish and Wildlife Service
USGS	United States Geological Survey
7Q10	A low flow that occurs for seven consecutive days in 10-year recurrence interval

A.2 Water use Management Plan and Map

IRRIGATION WATER MANAGEMENT PLAN

SAMPLE PLAN

Landowner's Objective

The landowner raises several varieties of potatoes for processing. Small grain is also raised on this farm, but its value as a cash crop is minimal. The purpose of the grain as a rotation crop is to help control erosion, maintain soil organic matter, and for disease and pest control. Irrigation takes place only on the fields in potato production.

This landowner's goals are to increase the net profit of his production and to reduce the risk of crop loss due to disease or drought. This grower contracts with a food processor before the growing season. The contract includes certain quality standards for the crop that influence the final price paid. The grower uses nutrient and pesticide management, in addition to soil and water management to achieve the crop quality standards and to increase marketable yields. Research by the University of Maine, McCains, and the grower's own experience has shown that supplemental irrigation can not only increase total yields, but also increase the quality, consistency, and value of the potato crop. Results of research by the Maine Agricultural Experiment Station on the benefits of supplemental irrigation are shown in the Crop Yield Response section of the Appendix

Healthy plants that are not stressed by drought are better able to resist disease. Inconsistent applications of water can cause misshapen tubers. The grower understands that excessive soil water can cause tuber rot. To reduce the potential for tuber rot, this grower will allow some moisture stress to the crop by applying less irrigation water than required to keep moisture near field capacity. This will allow capacity for natural rainfall between irrigation applications and reduce the chance of excess moisture. It will also reduce the volume of water that needs to be pumped and stored for irrigation.

This plan addresses the grower's objective of minimizing the risk of crop loss caused by drought. This area has experienced dry summers and extended periods of limited rainfall that have had significant effect on crop quality and yield. In some growing seasons, no supplemental irrigation is required, and in others, only two or three applications are necessary. The grower understands that water from the Meduxnekeag River is not always available for irrigation when flow rates are low since other designated uses, as determined by water quality standards or other regulations, could be impaired by irrigation water withdrawal. From his experience, rainfall records, and consultation with irrigation specialists, this grower has decided that 4 inches[1] of irrigation water available to the crop will be adequate for all but the driest years. He also understands and accepts the risk that in some very dry years, both the river and the proposed storage pond will not provide adequate water volume to insure the desired crop quantity and quality. This risk minimizes the area of wetlands that could be impacted by more or larger irrigation ponds.

Current and Future Irrigation Water Needs

Currently the landowner is irrigating approximately 100 acres on the Home Farm and 40 acres on the West Farm with a maximum annual net application of 4.0 inches. The pumping volume is based on a irrigation system efficiency of 75%. Irrigation system efficiency is the ratio of the amount of irrigation water available for crop production to the amount of irrigation water

[1] The amount of irrigation water available to the crop will vary according the growers needs. The quality of the crop and/or the dependability of the yield will determine the irrigation needs.

withdrawn from a water source. System efficiency includes conveyance losses to the field and uniformity of application. A travelling gun sprinkler irrigation system is the most practical and economically feasible system to use on both farms. Well managed, travelling gun sprinklers typically have a system efficiency of 75%. This results in a current maximum annual pumping volume of 44 acre feet on the Home Farm and 18 acre feet on the West Farm. The landowner's objective is to increase irrigation to a maximum of 190 acres on the Home Farm and a maximum of 84 acres on the West Farm which would result in maximum annual pumping volumes of 84 acre feet and 37 acre feet for the Home Farm and West Farm respectively.

Irrigation Water Management Plan Worksheets

The irrigation water management plan worksheets summarizes the management techniques that the landowner will be using to insure the most efficient use of irrigation water. Theoretically an application depth of up to 50% of the available water capacity could be applied per irrigation. However, it has been found by experience that applying lesser amounts more frequently and keeping the soil moisture level below field capacity is more effective for potato production. The time to irrigate is decided from soil moisture levels determined by methods shown in the worksheet. Applying lesser amounts more frequently minimizes losses from deep percolation and surface runoff, allows for storage in the root zone for rainfall, and can reduce tuber rot. A separate worksheet is shown for the landowner's two farms.

IRRIGATION WATER MANAGEMENT PLAN WORKSHEET
(Home Farm)

SAMPLE PLAN

OWNER	*Hypothetical*	PLANNER	*K. Roble*
TOWN	*New Limerick*	DATE	*25 April, 2000*
FARM NAME	*Home Farm*	TOTAL CROP ACRES	*332*

FIELD NUMBER	1	2	3
IRRIGATED ACRES	142	92	98
CROP TO IRRIGATE	Potatoes	Potatoes	Potatoes
EFFECTIVE ROOT DEPTH (in.)	15	15	15
AVAILABLE WATER CAPACITY (in.)	2.91	2.91	2.91
PEAK CONSUMPTIVE USE (in/day)	.17	.17	.17
CROP ROTATION	Potatoes/grain	Potatoes/grain	Potatoes/grain
PREDOMINATE SOIL TYPE	Linneus	Linneus	Linneus
GROSS WATER APPLIED PER IRRIGATION (in.)	0.75	0.75	0.75
NET WATER APPLIED PER IRRIGATION (in.)	0.56	0.56	0.56
WATER USE / APPLICATION (ac-ft)	8.9	5.8	6.1
PLANNED PUMPING RATE (gpm)	450	450	450
LANDOWNER'S SEASONAL NET WATER NEEDS (in)	4	4	4
SEASONAL WATER PUMPED (NET/GROSS, ac-ft)	47/63	31/41	33/43
SCHEDULING METHOD	Checkbook and feel methods	Checkbook and feel methods	Checkbook and feel methods
TYPE OF SPRINKLER	Travelling gun	Traveling gun	Traveling gun
SYSTEM EFFICIENCY (%)	75	75	75
POTENTIAL WATER SOURCES	A,B,D,E	A,B,D,E	A,B,D,E,G

NOTES:

Of the total crop acres on this farm, crops will be rotated so that no more than 190 acres will require irrigation in any one year. The maximum gross seasonal irrigation water needs for this farm will be 84 ac-ft.

SAMPLE PLAN

IRRIGATION WATER MANAGEMENT PLAN WORKSHEET
(West Farm)

OWNER	*Hypothetical*	PLANNER	*K. Roble*
TOWN	*New Limerick*	DATE	*25 April, 2000*
FARM NAME	*West Farm*	TOTAL CROP ACRES	*146*

FIELD NUMBER	*4*	*5*	
IRRIGATED ACRES	*84*	*50*	
CROP TO IRRIGATE	*Potatoes*	*Potatoes*	
EFFECTIVE ROOT DEPTH (in.)	*15*	*15*	
AVAILABLE WATER CAPACITY (in.)	*2.91*	*2.91*	
PEAK CONSUMPTIVE USE (in/day)	*.17*	*.17*	
CROP ROTATION	*Potatoes/grain*	*Potatoes/grain*	
PREDOMINATE SOIL TYPE	*Linneus*	*Linneus*	
MAX. GROSS WATER APPLIED PER IRRIGATION (in.)	*.75*	*.75*	
WATER USE / APPLICATION (ac-ft)	*5.3*	*3.1*	
PLANNED PUMPING RATE (gpm)	*450*	*450*	
LANDOWNER'S SEASONAL NET WATER NEEDS (in.)	*4*	*4*	
SEASONAL WATER PUMPED (NET/GROSS, ac-ft)	*28/37*	*17/23*	
SCHEDULING METHOD	*Checkbook and feel methods*	*Checkbook and feel methods*	
TYPE OF SPRINKLER	*Travelling gun*	*Travelling gun*	
SYSTEM EFFICIENCY (%)	*75*	*75*	
POTENTIAL WATER SOURCES	*C,F*	*C,F*	

NOTES:
Of the total crop acres on this farm, crops will be rotated so that no more than 84 acres will require irrigation in any one year. The maximum gross seasonal irrigation water needs for this farm will be 37 ac-ft.

SAMPLE PLAN

Alternative Analysis

The Proposed and Potential Water Sources Worksheet summarizes all of the possible water sources that are available to meet the landowner's irrigation water needs. A separate worksheet is provided for each farm or farm unit. The notes following each worksheet states the potential of each source and discuss the impacts of using the sources for irrigation withdrawals. The alternative chosen will best meet the irrigation water requirements as stated in the objectives while minimizing the impacts on wetland, ponds, or streams.

PROPOSED AND POTENTIAL WATER SOURCES WORKSHEET

Home Farm

LANDOWNER	*Hypothetical*		
FARM NAME	*Home Farm*		
TOWN	*New Limerick*		
PLANNER	*K. Roble*	DATE	*April 25, 2000*

SITE NUMBER	A	*B*	*D*
TYPE OF SOURCE	*Meduxnekeag River*	*Proposed embankment pond*	*Potential embankment/ excavation pond*
DRAINAGE AREA	*31 sq. mi.*	*286 acres*	*100 acres*
PUMPING RATE (cfsm) (river or stream)	*.032*	-	-
STORAGE CAPACITY (ac-ft)	-	*40-48*	*35*
MAXIMUM DEPTH (ft)	-	*13*	*10*
POOL AREA (ac)	-	*9*	*9*
MAXIMUM FILL HEIGHT (ft)	-	*18*	*12*
EMBANKMENT LENGTH (ft)	-	*600*	*400*
VOLUME OF FILL (cy)	-	*14,000*	*5,000*
SOIL TYPE	-	*Monarda*	*Monarda*
WETLAND ACRES	-	*6.5*	*9*

Site B: An embankment pond with a storage capacity of 40 acre feet is being proposed at this time. If suitable soil is available from the pool area, the embankment could be expanded to add approximately an additional 8 acre feet of storage capacity. An intermittent stream feeds this site.

Site D: Not proposed as a water source at this time, since more wetland would be affected for less storage. An excavated pond in the wetland is possible, but it would be costly to obtain significant storage capacity. One acre-foot of volume is about 1600 c.y. of excavation, in addition to the overburden that would need to be removed.

Site E: Potentially could be expanded, but the site is relatively small. The existing pond may be used as a water supply for one application on about 70 acres. Recharge would likely be slow, since the site is high on the watershed.

Site G: A potential excavated pond in a wooded wetland. Monarda soils generally have a perched water table near the surface October-May. Unless test pits confirm a consistent high water table or a recharging spring, this site is not suitable. The watershed is not large enough to support a water supply from surface runoff.

The Significant Sand & Gravel Aquifer Map identifies an aquifer just east of the farm. The aquifer is mapped as greater than 50 gpm, but it is unknown if it could support 450 gpm. Also, the aquifer is located adjacent to the river, so likely, water withdrawal would essentially be removed from the surface flow.

PROPOSED AND POTENTIAL WATER SOURCES WORKSHEET

West Farm

LANDOWNER	*Hypothetical*		
FARM NAME	*West Farm*		
TOWN	*New Limerick*		
PLANNER	*K. Roble*	DATE	*April 25, 2000*

WATER SOURCE	C	*F*	
TYPE OF SOURCE	*Existing pond*	*Meduxnekeag River*	
DRAINAGE AREA	*20 acres*	*30 sq. miles*	
PUMPING RATE (cfsm) (river or stream)		*0.033*	
STORAGE CAPACITY (ac-ft)	*16*	-	
MAXIMUM DEPTH (ft)	*12*	-	
POOL AREA (ac)	*2*	-	
MAXIMUM FILL HEIGHT (ft)	*NA*	-	
EMBANKMENT LENGTH (ft)	*NA*	-	
VOLUME OF FILL (cy)	*NA*	-	
SOIL TYPE	*Linneus, Monarda*	-	
WETLAND ACRES	*NA*	-	

PROPOSED AND POTENTIAL WATER SOURCES WORKSHEET
Home Farm (continued)

LANDOWNER	*Hypothetical*		
FARM NAME	*Home Farm*		
TOWN	*New Limerick*		
PLANNER	*K. Roble*	DATE	*April 25, 2000*

WATER SOURCE	E	G	
TYPE OF SOURCE	*Existing excavated pond*	*Potential excavated pond*	
DRAINAGE AREA	*4 acres*	*30 acres*	
PUMPING RATE (cfsm) (river or stream)		-	
STORAGE CAPACITY (ac-ft)	5	*8*	
MAXIMUM DEPTH (ft)	6	*10*	
POOL AREA (ac)	*1*	*1*	
MAXIMUM FILL HEIGHT (ft)	*0*	-	
EMBANKMENT LENGTH (ft)	*NA*	-	
VOLUME OF FILL (cy)	*NA*	*16,000 excavation*	
SOIL TYPE	*Monarda*	*Monarda*	
WETLAND ACRES	*0*	*1*	

NOTES:

Total supplemental irrigation water needs for the Home farm is 84 ac-ft. Approximately 50 ac-ft of storage will be available between the existing pond at Site E and the proposed pond at Site B. The remaining 34 ac-ft of irrigation water for the proposed system will come from the Meduxnekeag River at Site A . The grower has been pumping as much as 44 ac-ft from the river. Therefore, the proposed pond at Site B should result in less water needed from the Meduxnekeag River. The grower plans to minimize the effects on both the Meduxnekeag River and the wetlands at Site B by irrigating from the river when flows are not low and using pond storage when river flows are low. This reduces the size of the pond and the area of wetland impact. If future regulations restrict direct pumping from the river, additional storage will be required. For information, when the river is flowing at 0.3 cfsm, irrigation withdrawal will be 10% of the flow. Any irrigation water withdrawals will not result in a violation of designated uses of any water body. All potential water sources are described below.

Site A: Existing source of water, pumping at 450 gpm has provided a maximum yearly volume of 44 ac-ft., however, in two of the last 6 years, pumping had to be suspended at times due to low stream flows.

NOTES:

Total supplemental irrigation water needs for this farm is 37 ac-ft.

Site C: An existing embankment/excavated pond. This pond was constructed below a spring in glacial till soils, but has a slow recharge. The pond currently provides most of the irrigation water supply.

Site F: The grower uses the river when flows are not low. The proposed expanded irrigation water needs will come from the Meduxnekeag River at this site. Any irrigation water withdrawals will not result in a violation of designated uses of the stream. For information, when the river flow is 0.33 cfsm at this location, 10% is removed at the pumping rate of 450 gpm.

There are no mapped significant aquifers on this farm. Water yields from bedrock wells are much too low for irrigation.

Summary

All proposed irrigated acres for the landowner are included in this irrigation water management plan. The plan consists of two farms that have separate water sources. The supplemental irrigation water needs shown for both farms are the maximum amounts that would be needed depending on the crop rotation. Annually the combined acres in potato production from both farms will be approximately 50% of the total combined acreage.

From experience, the landowner's potato quantity and quality of production goals are met by being able to apply a seasonal net of 4 inches of supplemental irrigation. Therefore, the planned irrigation water supplies for each farm is the volume needed to provide a net application of 4 inches on all acres in potato production. The proposed water supplies are considerably less than the theoretical net of 6.5 inches of supplemental irrigation that would be needed to guarantee that the consumptive use requirements are met 8 years out of 10. Providing water supplies that insure a supplemental net irrigation of only 4 inches will help minimize the effect on surface streams, wetlands, and ground water supplies.

At this time the only proposed additional water supply development is the embankment pond at Site B for the Home Farm. The pond will have an effect on 6.5 acres of wetland. A total of 50 acre feet of storage will be provided by ponds at sites B and E. The remaining 34 acre feet of water needed for the Home Farm will come from the Meduxnekeag River at Site A. In the future if these three sources are not adequate to supply the supplemental irrigation water needs, then the ponds at Sites D, E, and G would be developed. The river will be used during higher flow rates when irrigation withdrawals will not cause an adverse impact on the stream habitat. The ponds will be used during low flow periods. The pond at Site B will be filled when a high flow rate occurs in the intermittent stream supplying the pond.

At this time the existing water sources will be used for all of the supplemental irrigation water needs for the West Farm. Management techniques will be similar to the Home Farm by using the river source during high flows and using the pond source during low flows. Other sources not mentioned in this plan would have to be found if the existing sources do not meet the landowner's crop production objectives.

Appendix

SAMPLE PLAN

Crop Yield Response

Several studies of supplemental irrigation of potatoes in Maine between 1956 and 1989 showed increases in total yield of 25 to 130 cwt./acre with the conclusion that irrigation will optimize yields and insure quality in about three out of every four years. Research by the Maine Agricultural Experiment Station for the Aroostook Soil and Water Management Board reported U.S. No. 1 potato yield increases of 25% and 40% respectively for the years 1994 and 1995 when 9.1 and 6.3 inches of rain fell in June through August. The four-year study, averaging the four potato varieties tested, predicted the 10-year average yield increase to be 48-cwt./acre total and 38 cwt./acre U.S. #1.

Crop Water Needs

Evapotranspiration is the sum of the evaporation of water from the soil and plant surfaces plus the water that transpires through the plant tissues. Therefore, evapotranspiration equates to the total water needs or consumptive use for plant growth. The University of Maine conducted supplemental irrigation studies on four potato varieties at the Aroostook Farm in Presque Isle from 1992 through 1997. Estimated total annual crop evapotranspiration (Et_c), assuming adequate soil moisture, ranged from 12.0 to 15.1 inches for the first four years of the study. Calculations of average evapotranspiration for potatoes in Central Aroostook by the radiation method using mean monthly climate values fall within the range of the study. The results of these calculations are included in Table 1. The actual evapotranspiration may vary depending on potato variety, actual climate conditions, and any allowance for water stress by the crop. Supplemental irrigation is provided when rainfall does not meet the crop water needs.

Seasonal water needs determination

Table 1 summarizes the method used to determine the seasonal water needs for potatoes in central Aroostook county. The effective precipitation is the amount of mean rain that is stored in the root zone and is useable by the crop. The computations indicate that at least 6.7 inches of seasonal effective precipitation will occur 8 years out of 10. Statistically, 2 years in 10 will have less than 6.7 inches of effective precipitation. The net irrigation requirement is the difference between the average evapotranspiration and the effective precipitation. Traveling gun irrigation has an application efficiency of approximately 75%.

In theory, up to 8.7 inches of supplemental irrigation water would have to be available in order to meet the total potential water needs for potatoes in central Aroostook in 8 years out of 10. The calculated maximum net irrigation application (6.5 inches) coincides with the maximum amount of irrigation water applied by some irrigators (6 to 7 inches) in central Aroostook in 1995, a very dry year when less than 7 inches of rain fell in June, July, and August.

The maximum rain in 2 years in 10 and the minimum-recorded monthly rain shown in Table 1 are for information. The maximum rain in 2 years in 10 means that statistically, less monthly rain than the amount indicated will fall in 2 out of 10 years. The season total is not statistically correct.

The supplemental irrigation water needs depend on the objectives of the landowner. For example, 8.7 inches of water would have to be available for irrigation if it is necessary to insure full potential consumptive use requirements of the crop 8 years out of 10. Only 6.8 inches of irrigation water would be needed if the objective was to insure the mean or average consumptive use requirements.

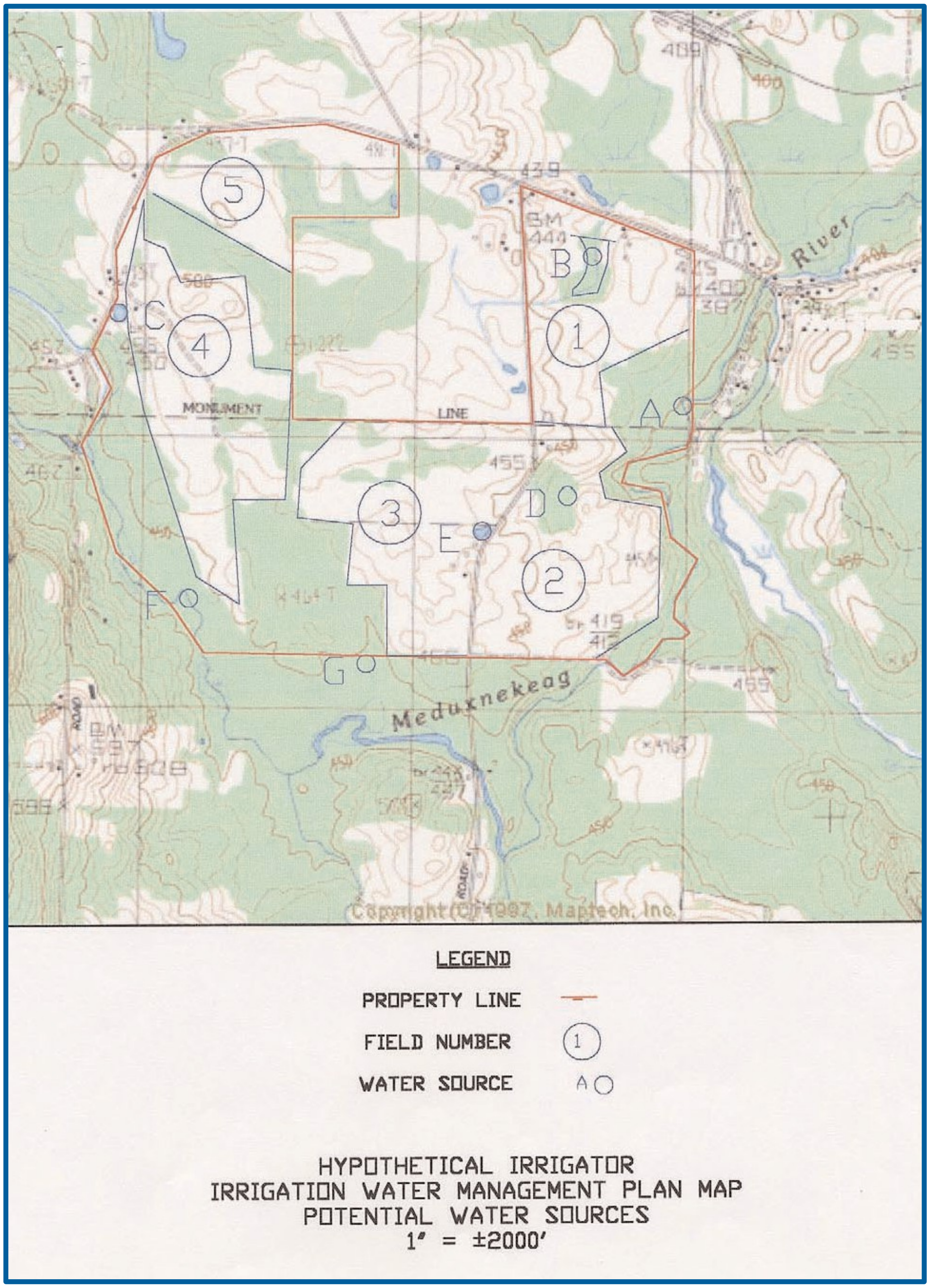
Table 1 (All data shown is in inches)

Month	½ May	June	July	August	½ Sept.	Season
ET_c	.92	2.52	4.69	3.96	1.09	13.2
Mean rain	1.56	2.91	4.01	4.07	1.72	14.3
Mean Effective Precipitation	.84	1.61	2.41	2.35	.93	8.1
Max. rain 2 years in 10	.96	1.83	2.98	2.64	1.09	9.5
Min. recorded rain[2]	.24	.88	1.75	.93	.43	9.0[3]

Mean net irrigation requirement	5.1
Mean gross irrigation requirement @ 75% efficiency	6.8
Minimum effective precipitation 8 years out of 10	6.7
Net irrigation requirement to insure seasonal Et_c 8 yrs. out of 10	6.5
Gross irrigation @ 75% efficiency to insure seasonal Et_c 8 yrs. out of 10	8.7

[2] Years of record: 1959-1988
[3] Seasonal precipitation for single year

SAMPLE PLAN


LEGEND
PROPERTY LINE
FIELD NUMBER
WATER SOURCE
HYPOTHETICAL IRRIGATOR
IRRIGATION WATER MANAGEMENT PLAN MAP
POTENTIAL WATER SOURCES
1" = ±2000'
Meduxnekeag
River
MONUMENT
LINE
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A.3 Maine Soils

Soil	Intake Rate or Maximum Application Rate (inches/hour)	Available Water Holding Capacity (Inch water/Inch soil)	Soil	Intake Rate or Maximum Application Rate (inches/hour)	Available Water Holding Capacity (Inch water/Inch soil))
Lovewell	0.5	5.9	Scantic	0.4	4
Lyman	0.6	2.6	Scio	0.5	3.6
Machias	0.6	1.95	Searsport	0.7	3.2
Madawaska	0.6	3.45	Sebago	0.6	6
Mapleton	0.5	2.2	Skerry	0.6	2.5
Marlow	0.5	2.85	Skowhegan	0.7	1.9
Masardis	0.6	1.9	Stetson	0.6	2.3
Melrose	0.6	2.7	Suffield	0.4	3.92
Merrimac	0.6	3	Sunday	0.7	1.3
Monadnock	0.6	2.9	Sutton	0.6	2.7
Monarda	0.5	3.5	Swanton	0.6	3.4
Monson	0.5	4.2	Swanville	0.5	4.8
Naumburg	0.6	1.5	Telos	0.5	5.2
Nicholville	0.5	3.6	Thorndike	0.5	2.05
Ninigret	0.6	3.5	Togus	0.6	6
Ondawa	0.6	3.4	Turnbridge	0.6	3.4
Paxton	0.6	2.9	Vassalboro	0.6	6
Perham	0.5	3.3	Washburn	0.5	4
Peru	0.5	2.75	Waskish	0.7	12
Plaisted	0.5	2.35	Waumbek	0.7	1.7
Podunk	0.6	3.4	Westbury	0.5	2.4
Redhook	0.5	2.6	Whately	0.7	3.6
Ridgebury	0.6	2.1	Windsor	0.8	1.55
Rifle	0.6	10.3	Winnecook	0.5	3.5
Rumney	0.6	3.8	Winooski	0.6	5.9
Salmon	0.5	3.2	Woodbridge	0.5	2.95

Properties of Specific Maine Soils

Soil	Intake Rate or Maximum Application Rate (inches/hour)	Available Water Holding Capacity (Inch water/Inch soil)	Soil	Intake Rate or Maximum Application Rate (inches/hour)	Available Water Holding Capacity (Inch water/Inch soil)
Adams	0.7	1.45	Conant	0.5	4
Agawam	0.6	3	Cornish	0.5	6.5
Allagash	0.6	3.5	Crary	0.5	3.2
Atherton	0.5	3.2	Creasey	0.6	2.6
Au Gres	0.7	1.6	Croghan	0.7	1.05
Bangor	0.5	3.71	Daigle	0.5	3.59
Becket	0.5	2.55	Deerfield	0.6	1.15
Belgrade	0.5	3.55	Dixfield	0.6	4.9
Benson	0.5	2.4	Dixmont	0.5	3.7
Berkshire	0.6	3	Duane	0.6	0.8
Biddeford	0.4	4.7	Easton	0.5	3.6
Boothbay	0.5	4	Eldridge	0.7	2.2
Brayton	0.6	4.5	Elloitsville	0.5	4.8
Burnham	0.5	7	Elmwood	0.6	3.45
Buxton	0.4	4.55	Fredon	0.5	3
Canaan	0.7	2.7	Fryeburg	0.5	6.3
Canandaigua	0.5	4	Hadley	0.5	5.95
Caribou	0.5	3.2	Halsey	0.5	4
Charles	0.5	6	Hartland	0.5	4
Charlton	0.6	3	Hermon	0.7	1.8
Chesuncook	0.5	5.8	Hinckley	0.7	1.3
Chocorua	0.6	11.2	Hollis	0.6	2.65
Colonel	0.6	4.1	Howland	0.5	4.1
Colton	0.8	1.27	Linneus	0.5	3.4

Properties of General Soil Types

Soil	Intake Rate or Maximum Application Rate (inches/hour)	Available Water Holding Capacity (Inch water/Inch soil)
Sand	0.7	0.065
Loamy Sand	0.55	0.085
Sandy Loam	0.55	0.11
Loam	0.55	0.15
Silt Loam	0.25	0.16
Silty Clay Loam	0.25	0.18
Clay Loam	0.25	0.17
Clay	0.2	0.16

A.4 Suggestions for Maine Irrigation Guide Updates

We welcome your suggestions, ideas, and improvements for our next update of the Maine Irrigation Guide.

Please fill out the form below and mail your comments to:

Tom Gordon
Agricultural Water Management Program
Maine Department of Agriculture, Conservation and Forestry
State House Station #22,
Augusta, ME 04333

Or send your comments in an email tom.gordon@maine.gov and include:

Name:	
Affiliation:	
Email:	
Phone:	
Chapter, Section, Page Number:	
Comments:	
General Comments or Thoughts:	