**RAW WATER FOR AGRICULTURAL IRRIGATION STUDY**
**PHASE 2**

# WATER CONSUMPTION STUDY

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Weather Innovations Incorporated

## 1.0 EXECUTIVE SUMMARY

This study presents measurements of soil and weather variables collected from July to September, 2006 in the tender fruit and grape growing regions of Niagara. Six automated weather stations were placed in peach orchards and vineyards within four designated districts of the Niagara region. At each site a profile of volumetric water content was measured using a capacitance probe while the meteorological variables included rainfall, temperature and solar radiation. All variables were recorded at 15 minute intervals throughout the study period.

Time series of soil volumetric water content at the 10, 30 and 50 cm depths are presented along with corresponding estimated total water content in the 0-60cm soil profile. This information was used to determine the crop coefficient (Kc) value for days following a rainfall event, and to determine the proportion of gross precipitation that infiltrates into the crop-root zone

Average 10-year return drought was calculated using data from the Environment Canada weather station in Vineland. In addition, potential evapotranspiration (ETo) was available for the growing seasons of 2003 to 2006. This information was used to determine the irrigation needs for tender fruit and vineyard growers in this region.

Based on average precipitation for the region (using data from 1970-2002) the water required by irrigation for the peach growing sites, Site 1, 2 and 11, using a drip irrigation system would be 145.4mm, 136.4mm, and 136.4mm, respectively. Using an overhead irrigation system, the water requirement increases to 179.6mm, 168.5mm, and 168.5mm. In a situation of a 1 in 10 year drought, the irrigation water for these sites using drip irrigation is 232.3mm (Site 1), and 223.3mm for Sites 2 and 11. For the grape growing sites, Sites 5, 8 and 17, the irrigation requirement using a drip irrigation system in an average precipitation year, is 14.4mm, 14.4, and 25.1mm. For an overhead irrigation system, the water needed is 17.8mm, 17.8mm, and 31.0mm. In a 1 in 10 year drought scenario, the water required for drip irrigation is 101.3mm, 101.3mm, and 112.0mm. For overhead irrigation the water needed increases to 125.2mm for Sites 5 and 8, and 138.4mm for Site 17.

## 2.0 INTRODUCTION

The Regional Municipality of Niagara engaged Stantec Consulting Ltd. (Stantec) to undertake a feasibility study for installing irrigation infrastructure in the Niagara Region. The “Feasibility Study” – Raw Water for Agricultural Irrigation Purposes” was completed in September 2005. The feasibility study identified several alternatives for developing irrigation infrastructure, provided order or magnitude costs, and highlighted opportunities and challenges facing the implementation of a regional irrigation project. The current Phase 2 assignment was the next step recommended in the implementation of this project.

Weather Innovations Incorporated (WIN) was asked to participate in the implementation of Phase 2 by providing regional climatological data and an analysis of irrigation consumption patterns in the targeted region. Prior to the assessment of an infrastructure suitable for the Niagara region, an assessment of the quantity of water requirements needed to be determined. Using state of the art weather monitoring equipment and an understanding of daily plant water requirements and soil water depletion rates, both calculated and monitored water requirements for grapes and peaches under the average season and 10 year return drought was undertaken.

## 3.0 WEATHER EQUIPMENT AND LOCATIONS

Farm sites were selected based on their regional distribution (Fig. 1, 2) and the location of a grape or peach crop. The regions were identified as, West District Zone A, West District Zone B, South District and East District, Table 1. A combination of automated weather stations, (Fig. 3) instrumented with temperature, relative humidity, precipitation and a specialized soil moisture instrument called a capacitance probes (C-Probes) (Fig. 4.) were used to provide continuous weather data while a manual station consisted of a soil moisture probe called a Diviner, requiring manual readings on a weekly basis. The Diviner data has not been included in this report. Two atmometers (Fig. 5) were installed to directly measure evapotranspiration. Data from the Environment Canada weather station located at the Vineland campus of the University of Guelph was used to calculate evapotranspiration using a modified Priestley-Taylor equation. Additional tipping bucket rain gauges (Fig.6) were located at various sites throughout the Niagara Peninsula test area to maximize the rainfall measurement coverage within the region.

**Fig. 1. Regions identified as: West District-Zone A, West District-Zone B, South District, East District.**

**Fig. 2. Weather station locations**

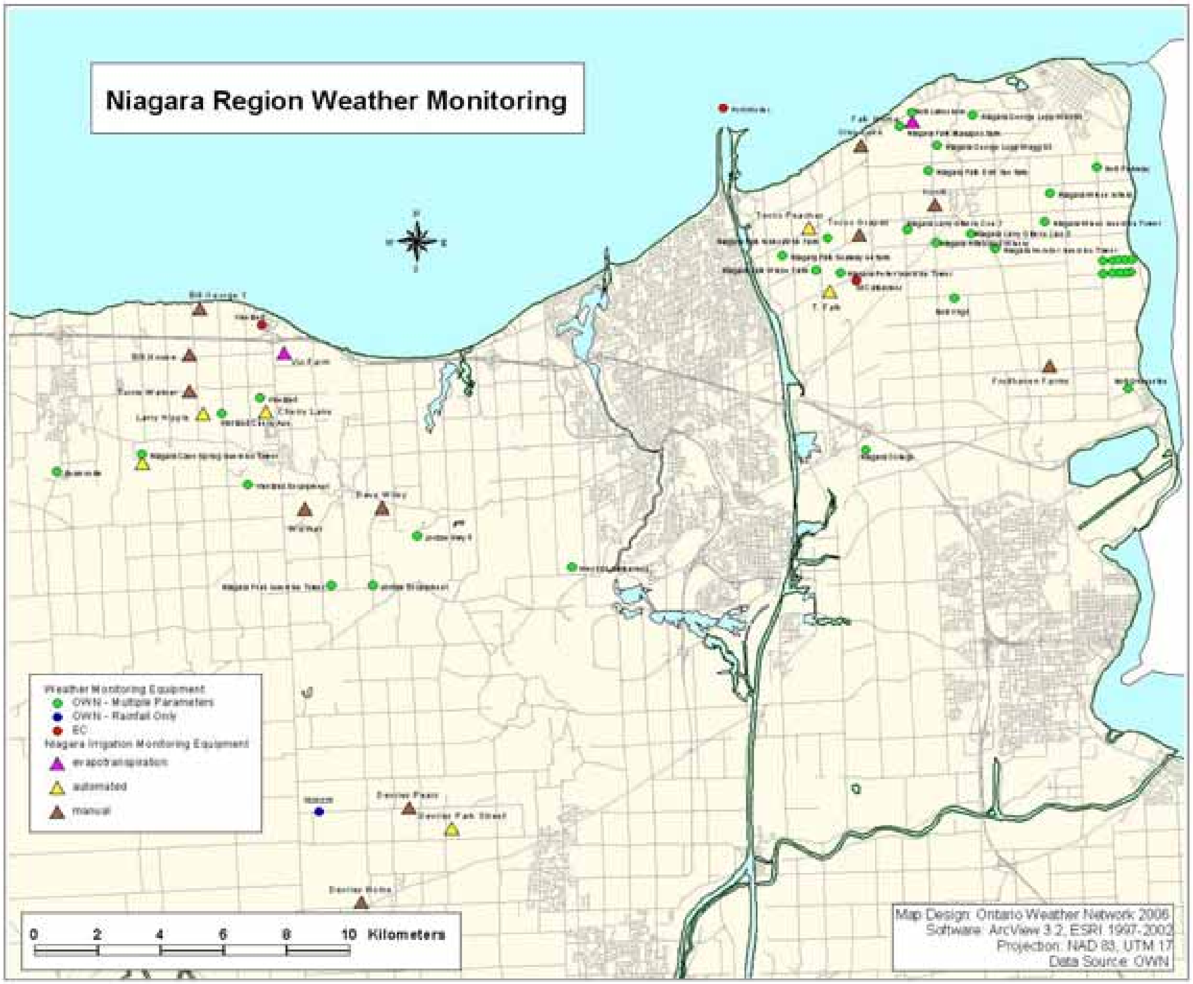


**Table 1. Weather station locations**

| Locations | Latitude | Longitude | Type | Crop |
|---|---|---|---|---|
| **West District- Zone A** | | | | |
| Site 1 | 43.16602 | -79.39769 | automated | Peach |
| Site 2 | 43.18279 | -79.39032 | automated | Peach |
| Site 3 | 43.18262 | -79.42742 | manual | Peach |
| Site 4 | 43.17239 | -79.42761 | manual | Peach |
| Site 5 | 43.16589 | -79.42235 | automated | Grape |
| Site 6 | 43.19587 | -79.42280 | manual | Grape |
| Site 7 | 43.18279 | -79.39032 | atmometer | |
| **West District – Zone B** | | | | |
| Site 8 | | | automated | Grape |
| Site 9 | 43.13820 | -79.38331 | manual | Grape |
| Site 10 | 43.13791 | -79.35323 | manual | Grape |
| **South District** | | | | |
| Site 11 | 43.04604 | -79.32859 | automated | Peach |
| Site 12 | 43.02551 | -79.36433 | manual | Peach |
| Site 13 | 43.05228 | -79.34505 | manual | Pear |
| **East District** | | | | |
| Site 14 | 43.215320 | -79.18474 | automated | Peach |
| Site 15 | 43.221146 | -79.13506 | manual | Peach |
| Site 16 | 43.238660 | -79.16344 | manual | Peach |
| Site 17 | 43.197030 | -79.17696 | automated | Grape |
| Site 18 | 43.213000 | -79.16508 | manual | Grape |
| Site 19 | 43.17451 | -79.09196 | manual | Grape |
| Site 20 | 43.245170 | -79.14346 | atmometer | |

**Fig. 3. Automated weather stations – Adcon Telemetry**

**Fig. 4. Capacitance Probe (C-probe)**

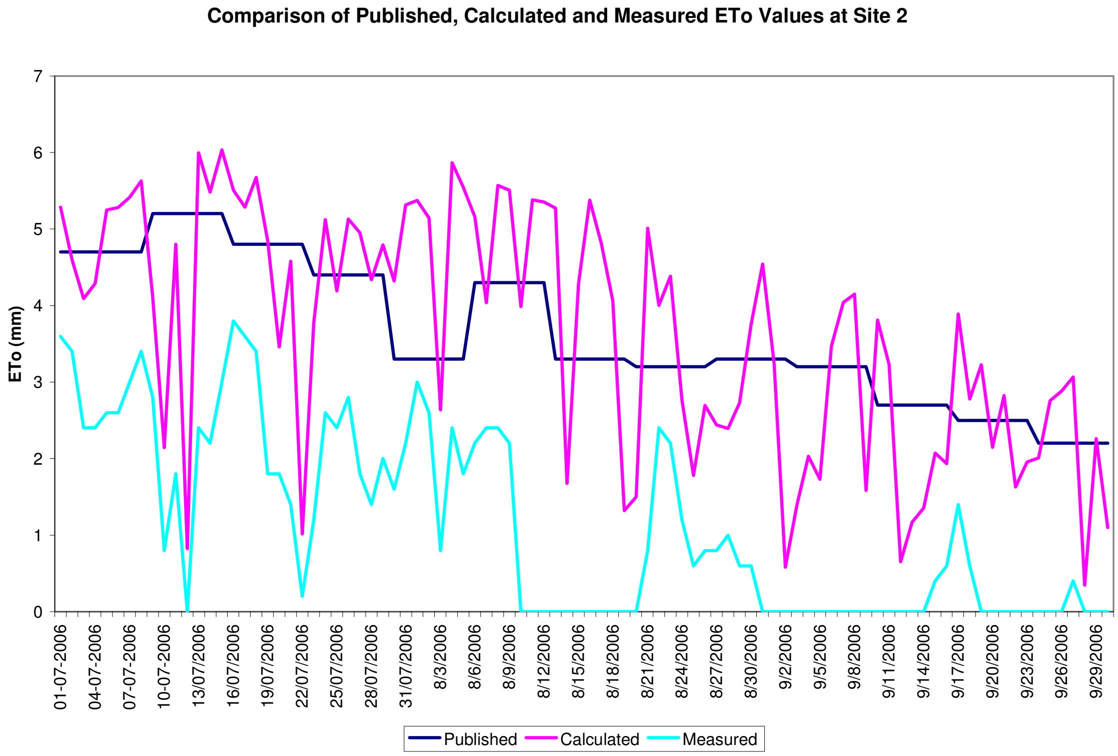
**Fig. 5. Atmometer to record direct evapotranspiration values ETo. Photograph from manufacture's website.**


**Fig. 6. Tipping bucket rain gauge - manual**

## 4.0 EVALUATING DAILY WATER CONSUMPTION FOR TENDER FRUIT AND GRAPES

Evapotranspiration, ET, is the combined water loss due to evaporation from the surface of the ground and the transpiration through the crop. ET for a given crop is calculated as the product of a standardized reference evapotranspiration (ETo) multiplied by a crop coefficient (Kc) (OMAFRA, 2004). ETo is the amount of water that would be lost from a well-watered 10 cm-high grass crop under a given set of meteorological conditions. Kc is an empirical factor to account for physiological and aerodynamic differences between the reference grass surface and the actual crop under consideration. For these reasons, Kc will change through the growing season when the plant reaches different growth stages. There are various ways to calculate ETo but all of them generally consider factors such as available energy to evaporate water, vapour pressure of the atmosphere and the magnitude of turbulent exchange processes. In this study ETo was calculated using a modified Priestley-Taylor equation. There are several sources that report Kc as shown in the Tables 9 and 10. Combining the meteorologically dependent ETo with the crop stage dependent Kc allows an estimate of daily crop water use. From this daily crop water use, total growing season plant water consumption can be calculated along with identifying periods of peak water demand.

**Fig. 7: Comparison of ETo values from published, calculated and measured determinations at the Site 2 location – 2006.**




**Published – OMAFRA, Calculated – Priestley-Taylor Model, Measured - Atmometer**

Daily ETo values are indicated in Table A1 of the appendix.

The ETo values published in the OMAFRA Guidelines to Irrigation Management are reasonably accurate during most of the days in July however they were not able to capture the unique events of this current year. For example during the rainy periods around July 10-14, the rate of transpiration and evaporation were significantly reduced as was the period around July 22-25. The measured ETo values from the commercial atmometer instrument consistently provided lower readings, and for periods in August and September indicates no evapotranspiration despite the instrument functioning according to manufacturer guidelines. Due to the fact that the atmometer measures ETo that are consistently lower than the calculated and published values, it is possible that a correction factor could be implemented. However, the use of such an instrument should be cautioned for commercial grower application.

The atmometer located at Site 20 was mal-functioning by the end of July, and as such the information is not useful for this study.

## 5.0 RAINFALL DATA

A number of tipping bucket rain gauges recorded rainfall throughout the summer at various sites. The following table lists 6 of the automated locations precipitation measurements. The only site which conducted overhead irrigation this season was at Site 11, where irrigation occurred on August 3.

The following precipitation data was used during subsequent components of the study for calculations of Kc values and determination of effective precipitation.

Graphical display of precipitation is shown in Fig. 8-12. Daily precipitation values are indicated in Table 2A in the appendix for each site.

## 6.0 SEASONAL SOIL MOSITURE

The soil moisture for each of the 6 automated sites is shown in Fig. 8A-13A . The soil moisture is displayed at each sensor level, 10 cm, 30 cm, and 50 cm as volumetric water content in $m^3m^{-3}$. In addition to the soil moisture at each sensor level, the integrated soil water or summed moisture quantities is displayed in Fig. 8B-13B. For the integrated soil water, each of the sensor levels was given equal weighting to be representative of the soil profile to a depth of 60cm, and has been converted into mm of water.

**Fig. 8A:** Volumetric soil water and rainfall for July 1 to September 24 at Site 1.

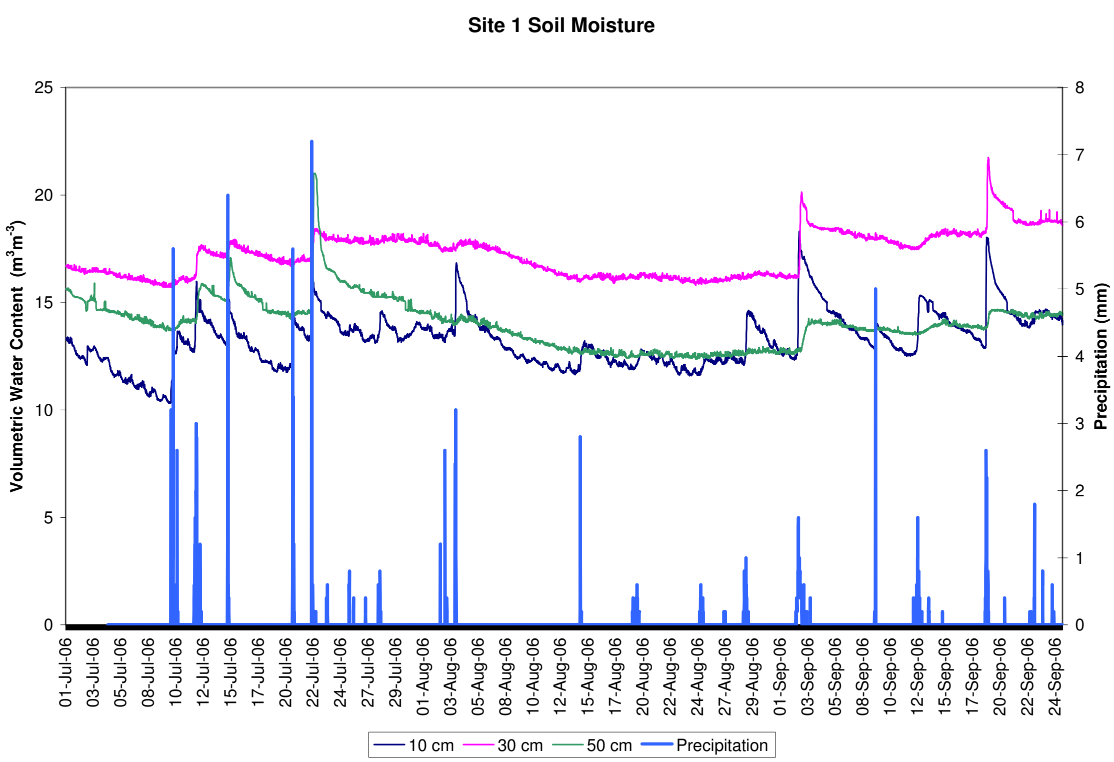


**Fig. 8B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 1.

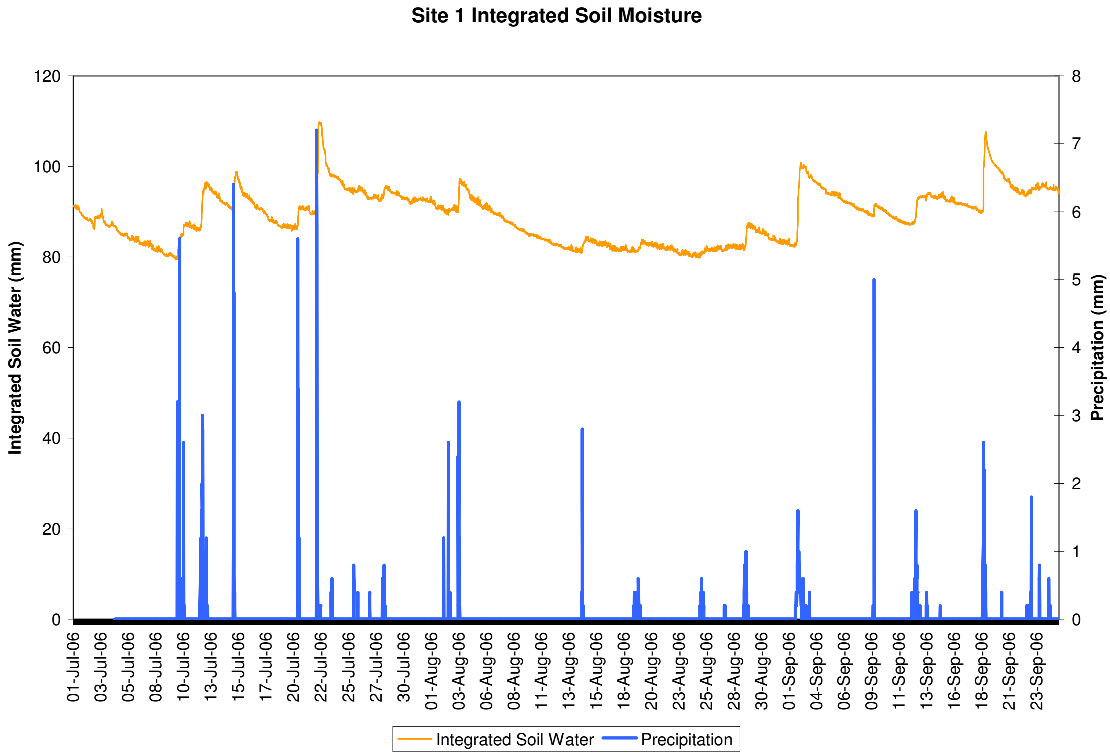


**Fig. 9A:** Volumetric soil water and rainfall for July 1 to September 30 at Site 2.

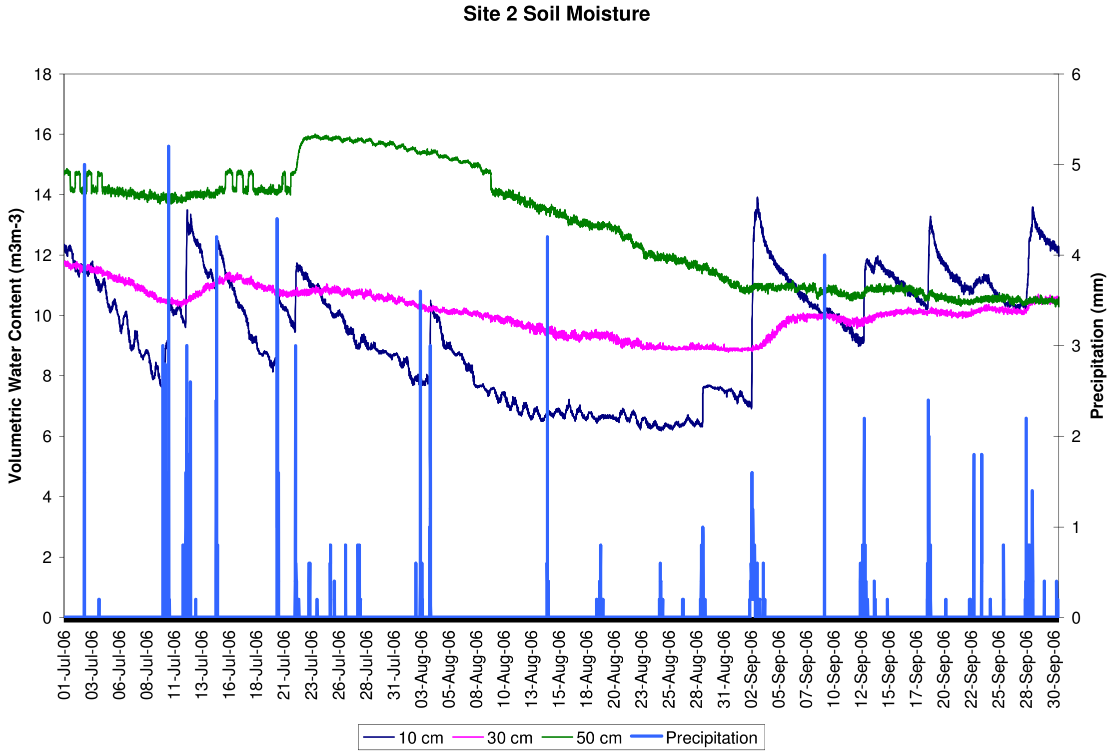



**Fig. 9B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 2.

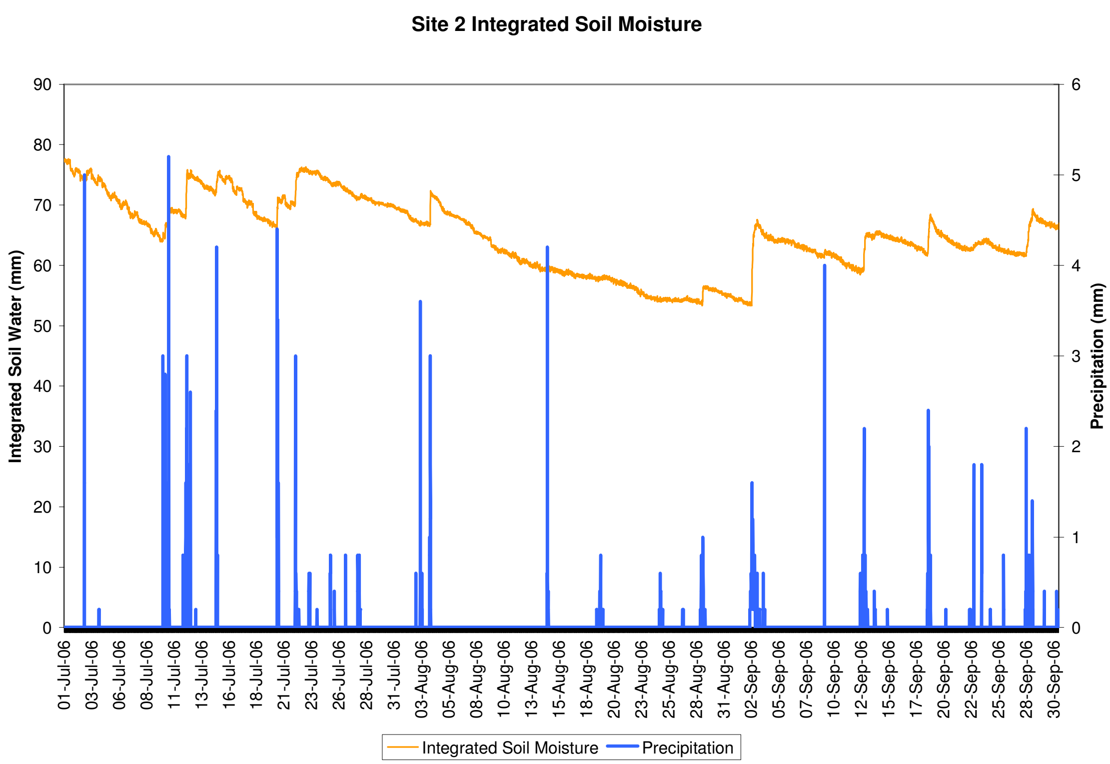


**Fig. 10A:** Volumetric soil water and rainfall for July 1 to September 30 at Site 5.

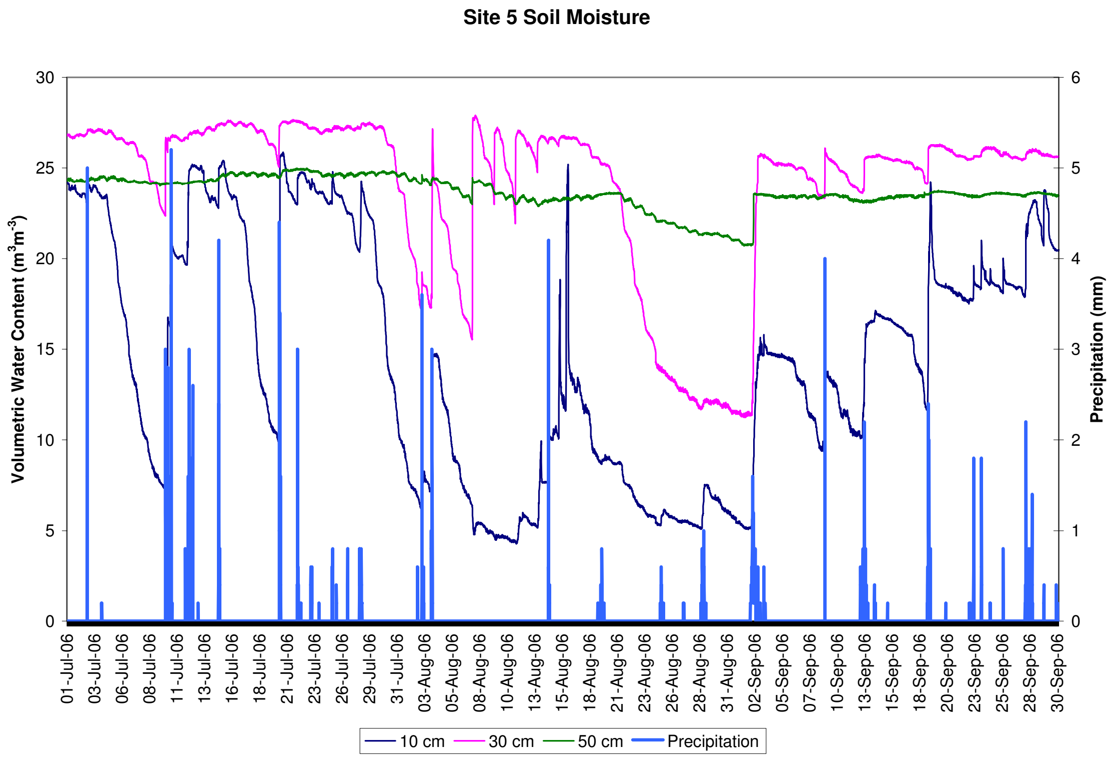


**Fig. 10B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 5.

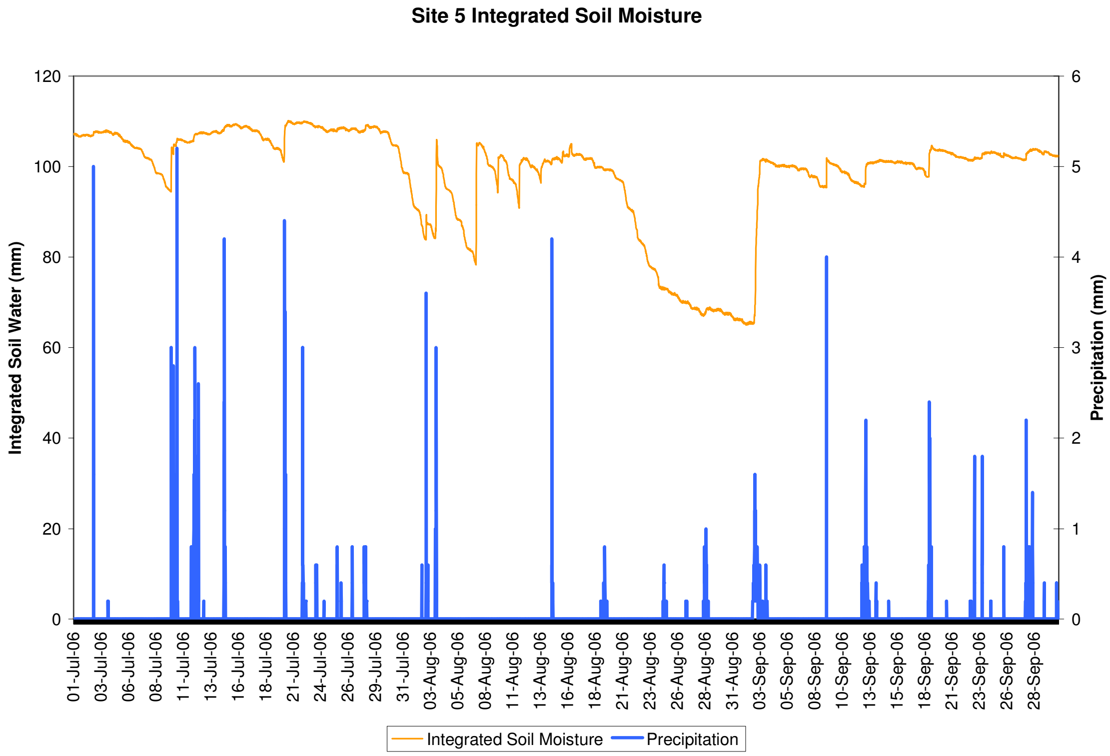


**Fig. 11A:** Volumetric soil water and rainfall for July 1 to September 30 at Site 8.

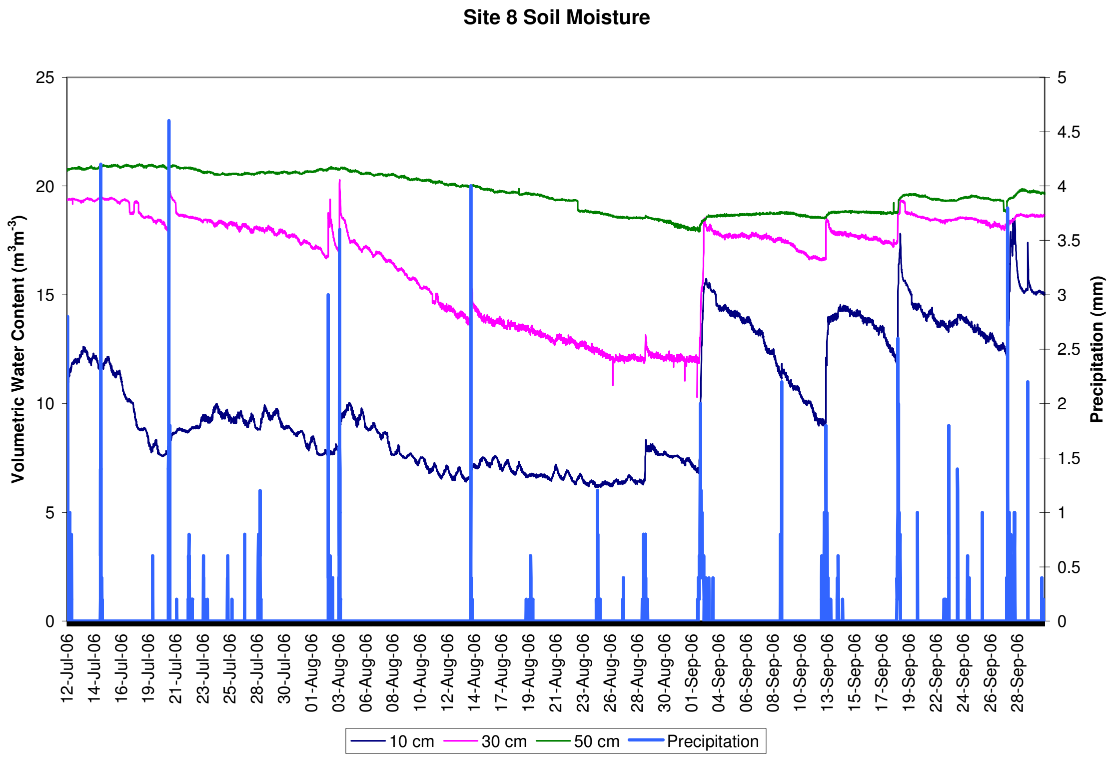



**Fig. 11B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 8.

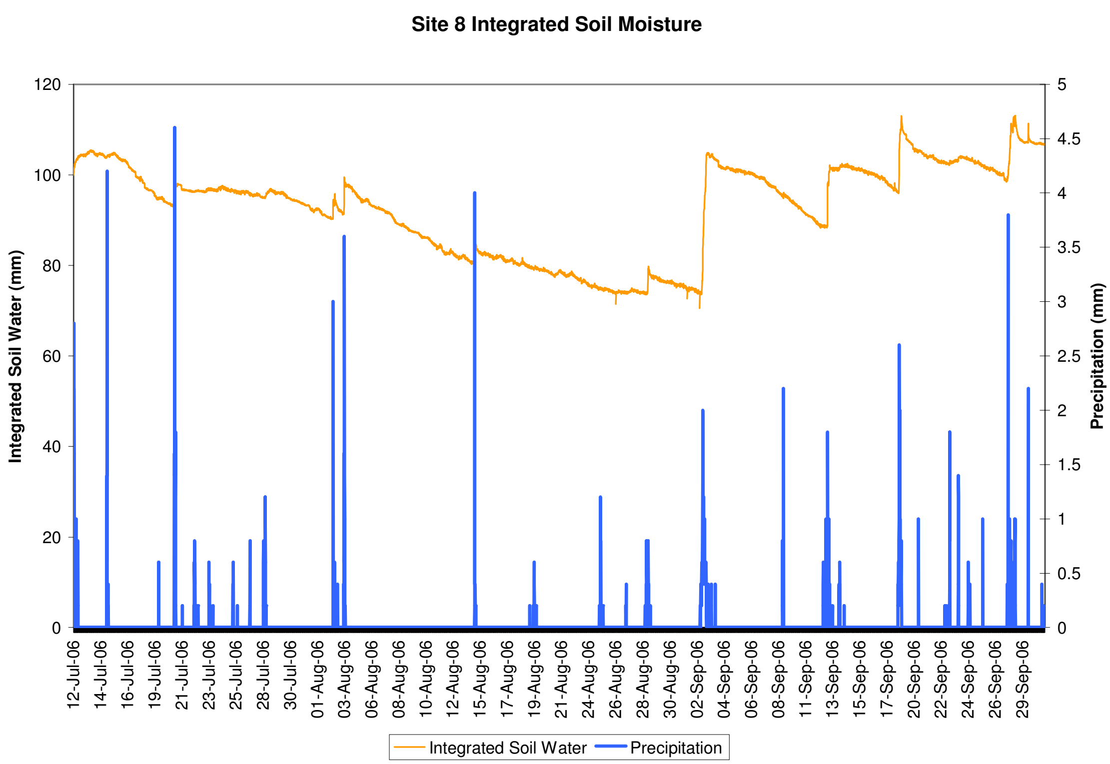


**Fig. 12A:** Volumetric soil water and rainfall for July 1 to September 30 at Site 11.

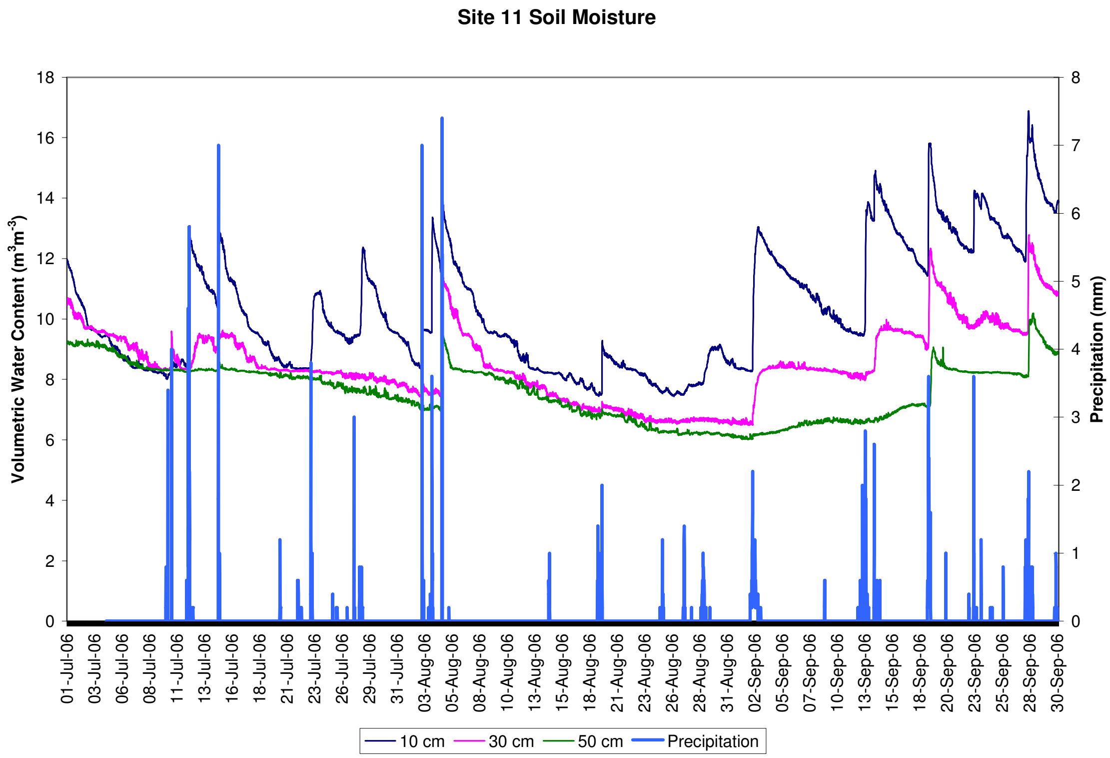


**Fig. 12B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 11.

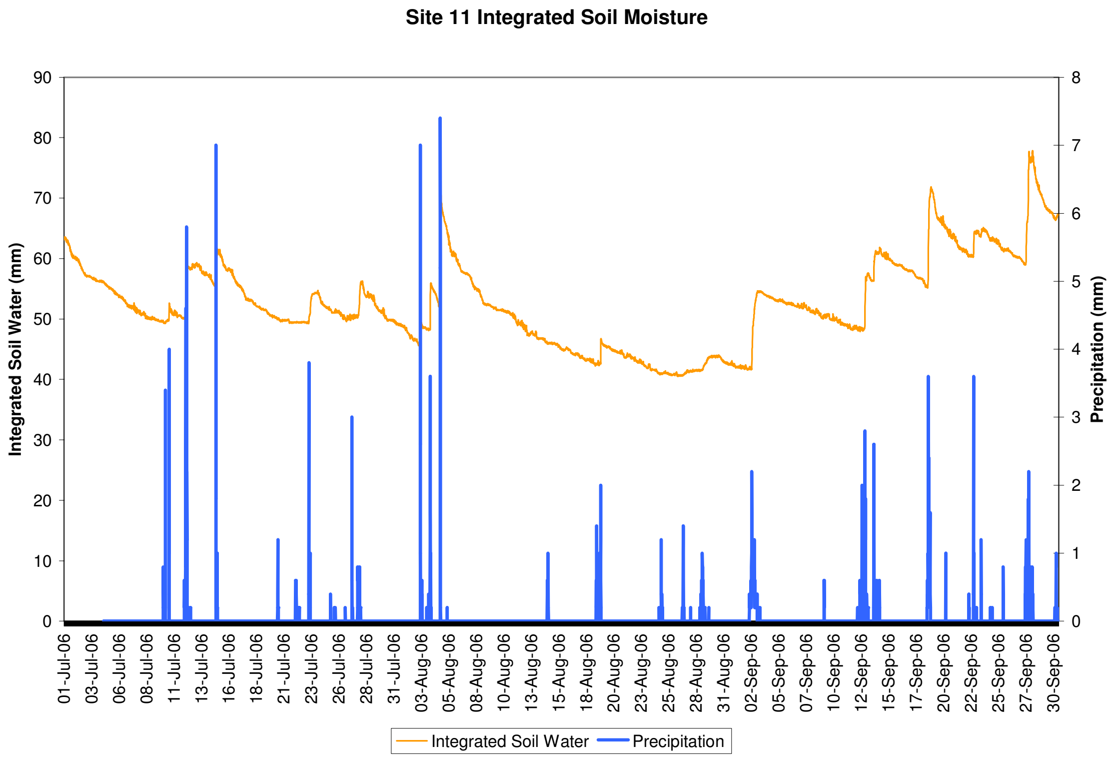


**Fig. 13A:** Volumetric soil water and rainfall for July 1 to September 30 at Site 17.

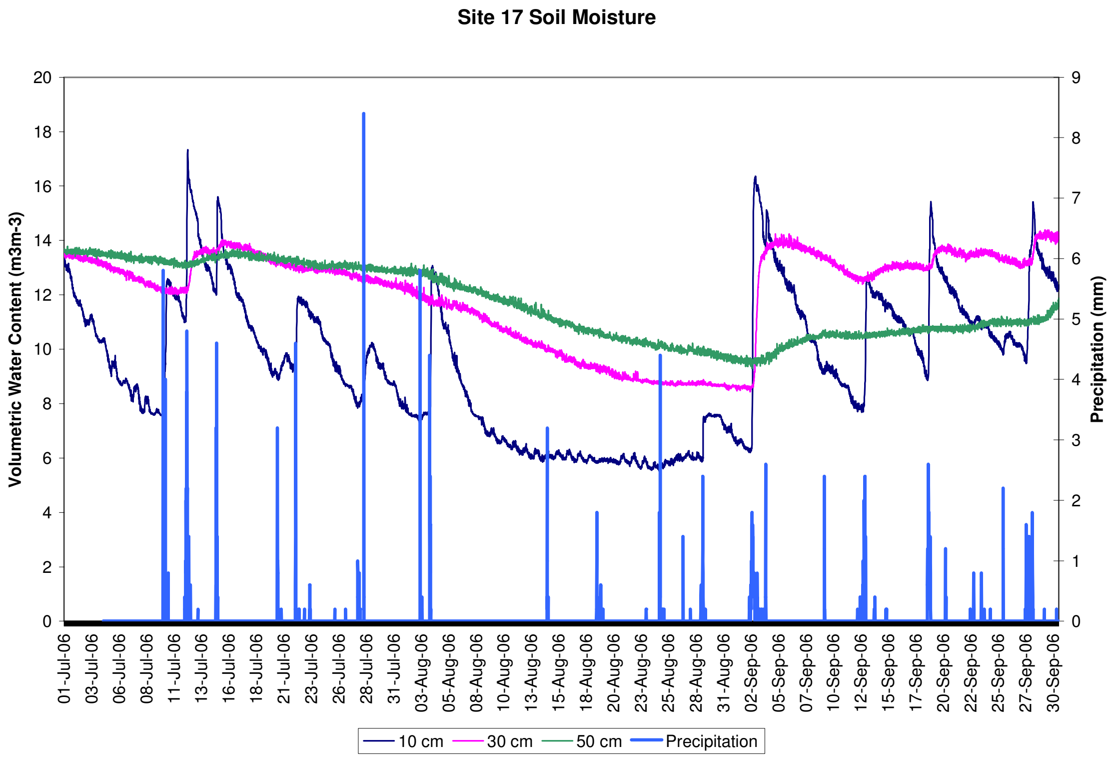
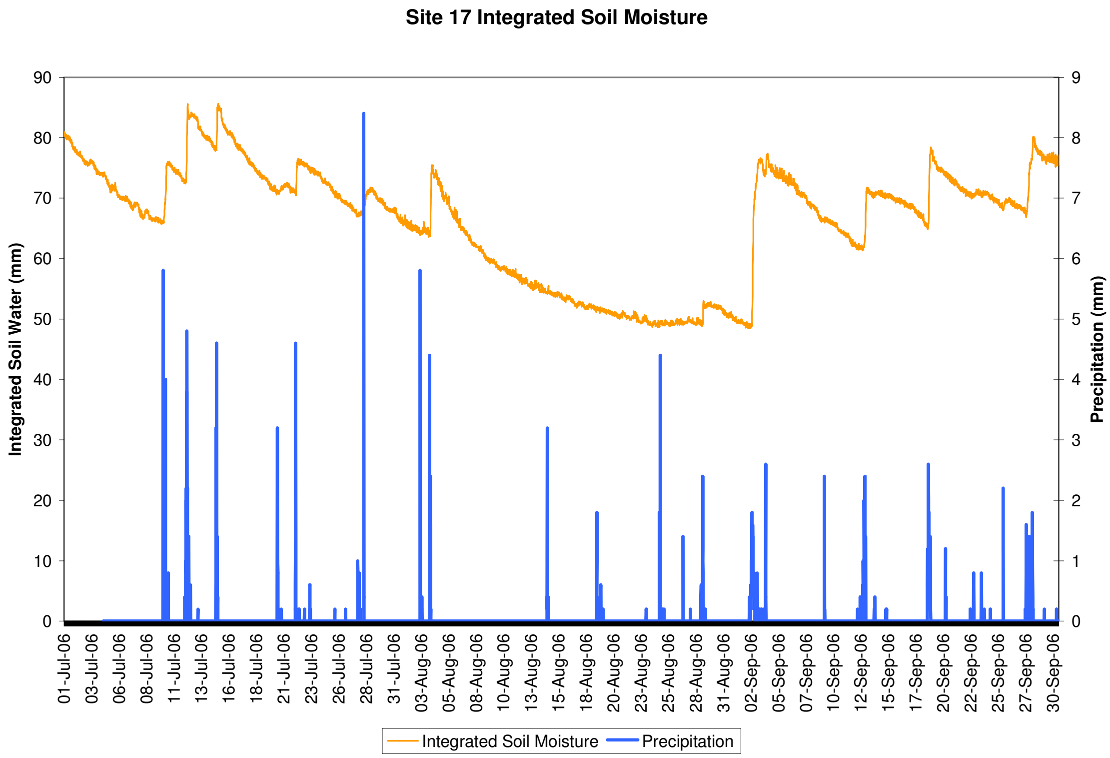


**Fig. 13B:** Integrated soil moisture for 60cm soil profile and rainfall at Site 17.




## 7.0 CROP COEFFICIENTS (Kc)

Discussion with Dr. Chin Tan at Agriculture and Agri-Food Canada in Harrow, Ontario resulted in establishing the Kc values the day following a rain event to be representative of the water used by the plant in relation to the maximum potential evapotranspiration losses.

The following tables indicate the calculated Kc values for each study site and rainfall events. Kc values were not calculated at Site 5 as data when irrigation occurred could not be provided. Since irrigation events would affect the quantitative soil moisture, Kc values would not be representative of normal daily water use.

To calculate the Kc values, the daily maximum soil water was determined, as well as the minimum soil water. The difference between these two values represents the water use for that day (ETc). The calculated ETo value was used as the maximum indicated water use and compared to the ETc indicated by the C-probe. The Kc value could be determined given that:

$$ETc = Kc*ETo$$

**Table 2:** Site 1 Kc value for Peaches

| Date | Maximum soil water | Minimum soil water | Water Use | ETo | Kc |
|---|---|---|---|---|---|
| July 11 | 87.92 | 85.68 | 2.24 | 4.8 | 0.47 |
| July 13 | 95.40 | 92.18 | 3.22 | 6.0 | 0.54 |
| July 16 | 94.18 | 90.82 | 3.36 | 5.5 | 0.61 |
| July 21 | 91.24 | 89.32 | 1.92 | 4.6 | 0.42 |
| July 24 | 97.88 | 94.72 | 3.16 | 5.1 | 0.62 |
| July 26 | 95.66 | 92.74 | 2.92 | 5.1 | 0.57 |
| July 29 | 94.56 | 92.70 | 1.86 | 4.8 | 0.39 |
| Aug. 4 | 96.96 | 92.50 | 4.46 | 5.9 | 0.76 |
| Aug. 15 | 84.52 | 82.58 | 1.94 | 4.3 | 0.45 |
| Aug. 20 | 83.72 | 82.16 | 1.56 | 1.5 | 1.04 |
| Aug. 26 | 82.54 | 81.26 | 1.28 | 2.7 | 0.47 |
| Aug. 30 | 86.58 | 84.62 | 1.96 | 3.8 | 0.52 |
| Sept. 4 | 96.94 | 94.92 | 2.02 | 2.0 | 0.99 |
| Sept. 10 | 90.74 | 88.56 | 2.18 | 3.8 | 0.57 |
| Sept 14 | 94.18 | 92.68 | 1.50 | 1.4 | 1.11 |
| Sept. 16 | 93.42 | 91.56 | 1.86 | 1.9 | 0.96 |
| Sept. 21 | 97.24 | 94.00 | 3.24 | 2.8 | 1.15 |

The Kc values for the remaining sites are found in Tables A3-A6 of the appendix.

The manufacturer of the C-probe indicates that 90% of the soil moisture measured is within 5cm of the sensor, and the maximum extent is 10cm. Being that soil moisture sensors are unable to measure the extent of a root system, their measurements are limited to their specific location.

A typical practice for the peach sites studied in the Niagara region, is a permanent sod strip between rows with an herbicide strip that extends to approximately 1.5 feet from the peach tree, or 1 foot from the grape vine. In this region, Dr. Tan suggests that the calculated Kc value using soil moisture data from the C-probe is representative of the evaporative losses and some of the losses due to transpiration from the plant, however, not the entire transpiration losses. Although the C-probe is excellent as a representative of the general trends in soil moisture for a broad area, in terms of water use by the plant, it is very site specific and may not represent the entire plant use. As a result, the soil moisture and thus the Kc coefficient should be more reflective of bare soil, which according to the Best Management Practices Irrigation Management Manual distributed by OMAFRA, has a Kc value of 0.2. The values indicated by the C-probe are comparable and slightly higher for several reasons. The C-probe is still located in the root zone of both the peach tree and grape vine, and as a result the Kc values indicate water use by the plant which is the result of transpiration and evaporative losses from the surface. We would expect under such conditions that the Kc value would range between that of bare soil and that of peach trees under clean cultivation, which have a Kc value for July and August of 0.65.

The use of soil moisture data to determine Kc values was especially difficult for sandy soil sites. There was additional ‘unaccountable’ soil moisture observed at many of these sites from the upward movement of water via capillary rise from the water table, especially in the month of August where effective precipitation was minimal. As a result, the change in soil moisture indicated by the C-probe may not be representative of the water actually used by the plant, resulting in a Kc value that is lower than anticipated.

In situations where the Kc value is greater than 1, the “water use” component is likely the result of both water use by the plant, evaporative losses, and drainage.

However, the Kc values determined in this study were within range of those published in the Best Management Practices Irrigation Management manual for bare soil with the influence of some plant use either by the crop or weed growth. We therefore recommend that the Kc values of 1.0 for peaches for July and August, and 0.95 during September is appropriate. As well, the published average Kc values for grapes of 0.8 be used for July and August, and 0.65 for September.

In comparison to the above Kc recommendations the following tables of published values are used for comparison.

Kc values for peaches have been published in the Best Management Practices Irrigation Management Manual for Ontario.

**Table 3**: Published Kc values for peaches

| | **July** | **August** | **September** |
|---|---|---|---|
| OMAFRA | 0.65 clean cultivation with cover crop<br><br>1.0 permanent sod with herbicide strip | 0.65 clean cultivation with cover crop<br><br>1.0 permanent sod with herbicide strip | 0.5 clean cultivation with cover crop<br><br>0.95 permanent sod with herbicide strip |

In the Niagara region, the majority of growers in this study have adopted the practice of permanent sod with herbicide strip.

Kc coefficients for grapes have also been published in many locations.

**Table 4:** Published Kc values for grapes.

| | **July** | **August** | **September** |
|---|---|---|---|
| British Columbia Lower Mainland/Vancouver Island | 0.65 | 0.65 | 0.65 |
| British Columbia Okanagan/Thompson | 0.80 | 0.85 | 0.80 |
| British Columbia | 0.85 | 0.90 | 0.80 |

| | | | |
|---|---|---|---|
| Kootenays | | | |
| FAO | 0.85 Table<br><br>0.70 Wine | 0.85 Table<br><br>0.70 Wine | 0.45 Table<br><br>0.45 Wine |

There is a general trend for Kc values to increase from July to September. This is the result of several factors. One is the water demand by the plant increases as fruit develops. In peaches, the water demand is greatest just prior to harvest. The second is the application of herbicides at the beginning of the season. By September, observations by a technician indicated increased weed growth with time. The growth of weeds subsequently increases the water demand within the herbicide strip.

## 8.0 CALCULATION OF EFFECTIVE PRECIPITATION

In order to calculate effective precipitation, the difference in soil moisture after a rain event was determined. As is customary in the BC Irrigation calculation of effective precipitation, the first 5 mm of the daily rainfall was removed to account for evaporative losses. The BC manual suggests multiplying the remaining value by 75% to account for losses such as runoff and deep percolation. The change in soil moisture in the soil was compared to the gross daily precipitation minus 5mm to determine if 75% is also applicable in this situation.

The values used to determine the average effective precipitation are found in Tables A7-A12 in the appendix.

With the first 5 mm of daily rainfall removed, the following efficiencies were obtained.

**Table 5**: Average efficiency of remaining water infiltration after evaporative losses have been removed from the daily gross precipitation

| | **Efficiency** | **Soil Type** |
|---|---|---|
| Site 1 | 83.0% | Silt Loam |
| Site 2 | 71.4% | Silt Loam |
| Site 5 | 91.4% | Clay |
| Site 8 | 88.5% | Clay |
| Site 11 | 73.4% | Silt Loam |
| Site 17 | 67.8% | Loam |
| Average | **79.3%** | |

The average percentage for the lighter soils is 73.9%, and 90% for clay soils. For the heavier clay soils, the proportion of gross precipitation that is effective is much higher than expected, as the infiltration capacity for clay soil is much less then for sandier soils. This could be for several reasons. Site 5 is a low lying location that receives the runoff of higher elevations. This increase in available water at the surface would not be detected by a rain gauge, however, there would still be water available to infiltrate into the soil. This is indicated by situations where the soil moisture increased more than the quantity of gross precipitation. The actual effective proportion of the true rainfall is likely lower than the 91.4%. It is also possible that the slope of the land influences the amount of water detected by the C-probe. The C-probe was located approximately 8 feet from a drainage grate. Likely the grate is positioned as such to prevent standing water. There could be lateral movement of water within the soil, or runoff along the surface that is infiltrating into the soil and is being detected by the C-probe, or flow through macropores.

Therefore overall calculation for effective precipitation for this study will be:

$$\text{Effective Precipitation} = (\text{Daily gross precipitation} - 5) * 0.79$$

## 9.0 AVERAGE AND 10-YEAR RETURN EFFECTIVE PRECIPITATION

Historical gross precipitation was examined from 1970 to 2002, for a total span of 30 years, given that data was not available for 1991, 1992, and 1993 for the Environment Canada Vineland weather station. From the daily data, the daily effective precipitation was calculated as indicated in Section 8.0. An average monthly value was obtained as a monthly value for a 10-year return drought.

Yearly historical effective precipitation for May, June, July, August and September can be found in Table A13 in the appendix.

**Table 6:** Average and 10-year return effective precipitation.

| | May | June | July | August | September |
|---|---|---|---|---|---|
| **Average** | 28.4 | 35.4 | 33.0 | 32.5 | 42.3 |
| **10-year return** | 9.6 | 13.0 | 12.6 | 5.5 | 16.7 |

For the purposes of this study which examines a period of the growing season from July 1 to September 30, the average effective precipitation is 107.8mm. The 1 in 10 drought risk effective precipitation is 34.8mm. These values will be used in the calculation of water demand required from irrigation.

## 10.0 IRRIGATION EFFICIENCIES

There are many published reports on ranges of irrigation efficiencies for various types of systems. However, there is some question as to the definition of irrigation efficiency in use when the calculations occur. Smajstrla et al. (2002) indicate that the definition of irrigation efficiency is based on how effective the irrigation system is at providing usable water to the crop. The overall irrigation efficiency would include the efficiencies of all components of the irrigation system, including factors such as reservoir storage and water application. However, all published data indicate a similar relationship regarding the difference in efficiencies between microirrigation and overhead irrigation.

There appears to be a large range in average efficiencies between many published sources.  However, all are in agreement that micro-irrigation, both surface and subsurface are the most efficient systems. Gun irrigation systems appear to be the least efficient as they are more apt to not have uniform water application and are very susceptible to water losses from wind and evaporation. It is important to note that some of these irrigation systems were tested in environments and on soils quite different from the Niagara area.

Well maintained (ideal management practices versus average management) irrigation systems, and water use during times where evaporation rates are lowest, would likely allow the irrigation systems indicated to be more efficient, to the point that they could operate under the higher published irrigation efficiency.

**Table 7:** Published average irrigation efficiencies

| | Evans et al. (1998) | Keller and Bliesner (1990) | Solomon (1988) | Rogers et al. (1997) | Smajstrla et al. (2002) | Clemments (2000) | SCC Kansas | Edwards Aquifer | Average |
|---|---|---|---|---|---|---|---|---|---|
| **Type** | **Efficiency** | | | | | | | | |
| Solid Set | 60-75% | 70-85% | | | 70-80% | 70-85% | 60% | | 74% |
| Centre Pivot | 80-85% | | 75-90% | 65-80% | 70-85% | 75-90% | 75-95% | | 80% |
| Linear Move | 65-85% | 70-85% | 75-90% | 60-70% | 70-85% | 75-90% | 75-95% | 50-60% | 77% |
| **Big Gun** | 55-65% | 60-75% | 65-75% | 75-90% | 60-70% | | 50% | 50-60% | **68%** |
| Traveler | 60-80% | 70% | 60-70% | 70-85% | 65-75% | 60-75% | 55% | 50-60% | 68% |
| **Micro (surface)** | 70-95% | | 75-95% | 75-95% | 70-90% | 85-90% | 98% | 90-95% | **84%** |
| **Micro (subsurface)** | | | | | 70-90% | 85-90% | 98% | 90-95% | **84%** |

## 11.0 CONCLUSIONS

The information used to determine the total amount of water required for irrigation purposes in the Niagara Peninsula needs to be based on calculations of water consumption using the published crop factor within the ETc calculation, and the effective precipitation for both the average and a 10 year drought effective precipitation quantity. For peaches, a crop coefficient of 1.0 was used for July and August, and 0.95 for September. For grapes, a crop coefficient of 0.8 was used for July and August, and 0.65 for September.

Daily ETo values were determined by averaging the daily values from 2003, 2004, 2005 and 2006. There is less variability from year to year in ETo values than there is in precipitation, and therefore an average for this study was appropriate.

**Table 8: Water requirements for peaches, May 1 - September 30.**

| | |
|---|---|
| Seasonal Evapotranspiration (ETc)* | 342.4mm |
| Average Effective Precipitation+ | 107.8mm |
| Required Water for Average Season | **234.6mm** |
| 10-year Return Precipitation+ | 34.8mm |
| Required Water for 10-year Return | **307.6mm** |

*Average calculated ETo values over 4 growing seasons, 2003, 2004, 2005 and 2006.
+ Based on precipitation data from 1970-2002.

**Table 9: Water requirements for grapes, May 1 – September 30.**

| | |
|---|---|
| Seasonal Evapotranspiration (ETc)* | 263.9mm |
| Average Effective Precipitation+ | 107.8mm |
| Required Water for Average Season | **156.1mm** |
| 10-year Return Precipitation+ | 34.8mm |
| Required Water for 10-year Return | **229.1mm** |

*Average calculated ETo values over 4 growing seasons, 2003, 2004, 2005 and 2006.
+ Based on precipitation data from 1970-2002.

In determining the amount of water required for a growing season, the assumption that the soil is at field capacity at the start of the growing season is typically made. The Ontario Best Management Practices Irrigation Manual offers average water capacity values for various soil types. This value multiplied by the rooting depth of the crop will provide a value of crop available soil water at field capacity. This value can be subtracted from the water demand. The rooting depth for peaches is 750mm, and for grapes, 900mm. As the soil types for the sites in this study were typically either loam, silt-loam, or clay, the value for crop available soil water is similar. Site 2, 5, 8, and 11 have a crop available soil water value of 120 mm for peaches, and 144mm for grapes. Sites 1 and 17, being lighter soils, have a crop available soil water value of 112.5mm for peaches, and 135mm for grapes.

Based on the average irrigation efficiencies for micro (surface and subsurface irrigation) (84%) and traveling or big gun irrigation (68%), the following water requirements would be needed in order to satisfy the crop demand based on average and 1 in 10 drought risk situations.

Tables 10 and 11 take into account the removal of additional water at the start of the growing season from the water demand, as well as the efficiency of the irrigation system.

**Table 10**: Irrigation water requirement for peaches under average precipitation and 1 in 10 drought precipitation situations.

| | **Peaches – Drip Irrigation** | **Peaches – Overhead Irrigation** |
|---|---|---|
| **Site 1** | | |
| Average Effective Precipitation | 145.4 mm | 179.6 mm |
| 1 in 10 drought Effective Precipitation | 232.3 mm | 286.9 mm |
| **Site 2** | | |
| Average Effective Precipitation | 136.4 mm | 168.5 mm |
| 1 in 10 drought Effective Precipitation | 223.3 mm | 275.9 mm |
| **Site 11** | | |
| Average Effective Precipitation | 136.4 mm | 168.5 mm |
| 1 in 10 drought Effective Precipitation | 223.3 mm | 275.9 mm |

**Table 11**: Irrigation water requirement for grapes under average precipitation and 1 in 10 drought precipitation situations.

| **Site 5** | Grapes – Drip Irrigation | Grapes – Overhead Irrigation |
|---|---|---|
| Average Effective Precipitation | 14.4 mm | 17.8 mm |
| 1 in 10 drought Effective Precipitation | 101.3 mm | 125.2 mm |
| **Site 8** | | |
| Average Effective Precipitation | 14.4 mm | 17.8 mm |
| 1 in 10 drought Effective Precipitation | 101.3 mm | 125.2 mm |
| **Site 17** | | |
| Average Effective | 25.1 mm | 31.0 mm |

| | | |
|---|---|---|
| Precipitation | | |
| 1 in 10 drought Effective Precipitation | 112.0 mm | 138.4 mm |

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## APPENDIX

**Table A1: Comparison between published ETo in-season calculated ETo and measured ETo values in July, August and September.**

| Month | Date | Published[1] ETo values | Calculated ETo[2] Priestley Taylor 2006 | Measured ETo Atmometer 2006 |
|---|---|---|---|---|
| | | West District Vineland | West –A, Site 2 | West - A, Site 2 |
| | | | | |
| **July** | 1 | 4.7 | 5.3 | 3.6 |
| | 2 | 4.7 | 4.6 | 3.4 |
| | 3 | 4.7 | 4.1 | 2.4 |
| | 4 | 4.7 | 4.3 | 2.4 |
| | 5 | 4.7 | 5.2 | 2.6 |
| | 6 | 4.7 | 5.3 | 2.6 |
| | 7 | 4.7 | 5.4 | 3.0 |
| | 8 | 4.7 | 5.6 | 3.4 |
| | 9 | 5.2 | 4.1 | 2.8 |
| | 10 | 5.2 | 2.1 | 0.8 |
| | 11 | 5.2 | 4.8 | 1.8 |
| | 12 | 5.2 | 0.8 | 0 |
| | 13 | 5.2 | 6.0 | 2.4 |
| | 14 | 5.2 | 5.5 | 2.2 |
| | 15 | 5.2 | 6.0 | 3.0 |
| | 16 | 4.8 | 5.5 | 3.8 |
| | 17 | 4.8 | 5.3 | 3.6 |
| | 18 | 4.8 | 5.7 | 3.4 |
| | 19 | 4.8 | 4.8 | 1.8 |
| | 20 | 4.8 | 3.5 | 1.8 |
| | 21 | 4.8 | 4.6 | 1.4 |
| | 22 | 4.8 | 1.0 | 0.2 |
| | 23 | 4.4 | 3.8 | 1.2 |
| | 24 | 4.4 | 5.1 | 2.6 |
| | 25 | 4.4 | 4.2 | 2.4 |
| | 26 | 4.4 | 5.1 | 2.8 |
| | 27 | 4.4 | 4.9 | 1.8 |
| | 28 | 4.4 | 4.3 | 1.4 |
| | 29 | 4.4 | 4.8 | 2.0 |
| | 30 | 3.3 | 4.3 | 1.6 |
| | 31 | 3.3 | 5.3 | 2.2 |
| **August** | 1 | 3.3 | 5.4 | 3 |
| | 2 | 3.3 | 5.1 | 2.6 |

| | | | | |
|---|---|---|---|---|
| | 3 | 3.3 | 2.6 | 0.8 |
| | 4 | 3.3 | 5.9 | 2.4 |
| | 5 | 3.3 | 5.5 | 1.8 |
| | 6 | 4.3 | 5.2 | 2.2 |
| | 7 | 4.3 | 4.0 | 2.4 |
| | 8 | 4.3 | 5.6 | 2.4 |
| | 9 | 4.3 | 5.5 | 2.2 |
| | 10 | 4.3 | 4.0 | 0 |
| | 11 | 4.3 | 5.4 | 0 |
| | 12 | 4.3 | 5.4 | 0 |
| | 13 | 3.3 | 5.3 | 0 |
| | 14 | 3.3 | 1.7 | 0 |
| | 15 | 3.3 | 4.3 | 0 |
| | 16 | 3.3 | 5.4 | 0 |
| | 17 | 3.3 | 4.8 | 0 |
| | 18 | 3.3 | 4.1 | 0 |
| | 19 | 3.3 | 1.3 | 0 |
| | 20 | 3.2 | 1.5 | 0 |
| | 21 | 3.2 | 5.0 | 0.8 |
| | 22 | 3.2 | 4.0 | 2.4 |
| | 23 | 3.2 | 4.4 | 2.2 |
| | 24 | 3.2 | 2.8 | 1.2 |
| | 25 | 3.2 | 1.8 | 0.6 |
| | 26 | 3.2 | 2.7 | 0.8 |
| | 27 | 3.3 | 2.4 | 0.8 |
| | 28 | 3.3 | 2.4 | 1 |
| | 29 | 3.3 | 2.7 | 0.6 |
| | 30 | 3.3 | 3.8 | 0.6 |
| | 31 | 3.3 | 4.5 | 0 |
| **September** | 1 | 3.3 | 3.2 | 0 |
| | 2 | 3.3 | 0.6 | 0 |
| | 3 | 3.2 | 1.4 | 0 |
| | 4 | 3.2 | 2.0 | 0 |
| | 5 | 3.2 | 1.7 | 0 |
| | 6 | 3.2 | 3.5 | 0 |
| | 7 | 3.2 | 4.0 | 0 |
| | 8 | 3.2 | 4.2 | 0 |
| | 9 | 3.2 | 1.6 | 0 |
| | 10 | 2.7 | 3.8 | 0 |
| | 11 | 2.7 | 3.2 | 0 |
| | 12 | 2.7 | 0.7 | 0 |
| | 13 | 2.7 | 1.2 | 0 |
| | 14 | 2.7 | 1.4 | 0 |

| | | | | |
|---|---|---|---|---|
| | 15 | 2.7 | 2.1 | 0.4 |
| | 16 | 2.7 | 1.9 | 0.6 |
| | 17 | 2.5 | 3.9 | 1.4 |
| | 18 | 2.5 | 2.8 | 0.6 |
| | 19 | 2.5 | 3.2 | 0 |
| | 20 | 2.5 | 2.1 | 0 |
| | 21 | 2.5 | 2.8 | 0 |
| | 22 | 2.5 | 1.6 | 0 |
| | 23 | 2.5 | 2.0 | 0 |
| | 24 | 2.2 | 2.0 | 0 |
| | 25 | 2.2 | 2.8 | 0 |
| | 26 | 2.2 | 2.9 | 0 |
| | 27 | 2.2 | 3.1 | 0.4 |
| | 28 | 2.2 | 0.3 | 0 |
| | 29 | 2.2 | 2.3 | 0 |
| | 30 | 2.2 | 1.1 | 0 |

/1 Published ETo values – OMAFRA Best Management Practices. Irrigation Management, Revised Edition, 2004
/2 Calculated ETo Priestley-Taylor

**Table A2: Rainfall data – July 1 to September 30, 2006 (mm)**

| Date | Day | West District – Zone A | | | West District – Zone B | South District | East District |
|---|---|---|---|---|---|---|---|
| | | Site 1 | Site 2 | Site 5 | Site 8 | Site 11 | Site 17 |
| | | | | | | | |
| **July** | 1 | 0 | 0.2 | 0 | 0 | 0 | 0 |
| | 2 | 0 | 6.6 | 5.8 | 3.4 | 0 | 0 |
| | 3 | 0 | 0.2 | 0 | 0 | 0 | 0 |
| | 4 | 0 | 0.2 | 0.4 | 1.2 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 20.8 | 20.0 | 22.8 | 21.4 | 10.2 | 15.0 |
| | 11 | 0 | 0.2 | 1.0 | 1.2 | 0 | 0 |
| | 12 | 26.4 | 28.4 | 34.4 | 28.8 | 30.4 | 32.6 |
| | 13 | 0 | 0.2 | 0 | 0 | 0 | 0.2 |
| | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 17.8 | 20.2 | 14.6 | 10.0 | 10.8 | 14.2 |
| | 16 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 19 | 0 | 0 | 0 | 0.6 | 0 | 0 |
| | 20 | 13.4 | 17.0 | 17.8 | 12.0 | 2.6 | 6.0 |
| | 21 | 0 | 0 | 0 | 0.2 | 0 | 0.2 |
| | 22 | 29.2 | 32.8 | 12.0 | 5.8 | 5.6 | 10.4 |
| | 23 | 2.0 | 1.8 | 2.6 | 2.6 | 11.0 | 1.8 |
| | 24 | 0 | 0.2 | 0 | 0 | 0 | 0 |
| | 25 | 3.0 | 2.4 | 3.6 | 2.0 | 0.6 | 0 |
| | 26 | 0 | 0.2 | 0 | 0 | 0.4 | 0.2 |
| | 27 | 0.8 | 1.2 | 1.6 | 1.0 | 3.8 | 0.2 |
| | 28 | 5.4 | 5.8 | 7.4 | 7.2 | 7.6 | 15.6 |
| | 29 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 31 | 0 | 0 | 0 | 0 | 0 | 0 |
| **August** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 4.2 | 4.6 | 4.6 | 3.8 | 10.6 | 6.6 |
| | 3 | 14.0 | 12.4 | 12.4 | 16.0 | 14.4 | 19.4 |
| | 4 | 0 | 0 | 0 | 0 | 23.6 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0.2 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 14 | 6.2 | 6.6 | 6.6 | 7.0 | 3.8 | 5.6 |
| | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 16 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 19 | 4.8 | 4.4 | 4.4 | 3.8 | 13.4 | 7.8 |
| | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 21 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 22 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 23 | 0 | 0 | 0 | 0 | 0 | 0.4 |
| | 24 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 25 | 3.0 | 3.0 | 3.0 | 3.8 | 3.4 | 9.4 |
| | 26 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 27 | 0.4 | 0.4 | 0.4 | 0.6 | 5.4 | 1.6 |
| | 28 | 4.4 | 4.4 | 4.4 | 4.8 | 5.0 | 3.4 |
| | 29 | 6.2 | 7.0 | 7.0 | 6.8 | 8.8 | 10.2 |
| | 30 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 31 | 0 | 0 | 0 | 0 | 0 | 0 |
| **September** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 27.8 | 28.0 | 28.0 | 34.4 | 36.2 | 36.4 |
| | 3 | 4.8 | 5.8 | 5.8 | 4.6 | 3.8 | 10.6 |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9 | 5.2 | 4.0 | 4.0 | 3.2 | 1.4 | 3.8 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 9.6 | 10.0 | 10.0 | 9.2 | 11.4 | 11.4 |
| | 13 | 5.8 | 6.0 | 6.0 | 7.4 | 21.8 | 10.8 |
| | 14 | 0 | 0.2 | 0.2 | 0 | 1.8 | 0.2 |
| | 15 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | 0.6 |
| | 16 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 18 | 15.6 | 14.4 | 14.4 | 17.8 | 19.2 | 18.6 |
| | 19 | 5.4 | 7.0 | 7.0 | 5.2 | 7.6 | 9.2 |
| | 20 | 0.4 | 0.2 | 0.2 | 0 | 1.0 | 1.8 |
| | 21 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 22 | 0.6 | 0.6 | 0.6 | 0.8 | 0.6 | 0.4 |
| | 23 | 4.4 | 5.8 | 5.8 | 6.2 | 8.0 | 3.0 |
| | 24 | 1.2 | 0.4 | 0.4 | 1.2 | 0.6 | 0.4 |
| | 25 | 0 | 1.0 | 1.0 | 1.0 | 1.2 | 3.4 |
| | 26 | - | 0 | 0 | 0 | 0 | 0 |
| | 27 | - | 5.6 | 5.6 | 9.0 | 5 | 5.4 |
| | 28 | - | 17.2 | 17.2 | 15.4 | 29.4 | 27.8 |
| | 29 | - | 0.6 | 0.6 | 2.2 | 0 | 0.2 |
| | 30 | - | 0.6 | 0.6 | 0.8 | 2.6 | 0.2 |

**Table A3**: Site 2 Kc calculation for peaches

| Date | Maximum soil water | Minimum soil water | Water Use | ETo | Kc |
|---|---|---|---|---|---|
| July 14 | 73.28 | 71.54 | 1.74 | 5.5 | 0.32 |
| July 16 | 74.86 | 71.64 | 3.22 | 5.5 | 0.58 |
| July 21 | 71.68 | 69.24 | 2.44 | 4.6 | 0.53 |
| July 26 | 73.92 | 72.32 | 1.6 | 5.1 | 0.31 |
| July 29 | 71.18 | 70.0 | 1.18 | 4.8 | 0.25 |
| Aug. 1 | 69.44 | 67.62 | 1.82 | 5.4 | 0.34 |
| Aug. 4 | 71.9 | 69.06 | 2.84 | 5.9 | 0.48 |
| Aug. 15 | 59.8 | 58.62 | 1.18 | 4.3 | 0.28 |
| Aug. 20 | 58.28 | 56.9 | 1.38 | 1.5 | 0.92 |
| Aug. 26 | 54.66 | 53.84 | 0.82 | 2.7 | 0.30 |

| | | | | | |
|---|---|---|---|---|---|
| Aug. 30 | 56.26 | 55.06 | 1.2 | 3.8 | 0.32 |
| Sept. 4 | 65.1 | 63.7 | 1.4 | 2.0 | 0.69 |
| Sept. 10 | 62.1 | 60.16 | 1.94 | 3.8 | 0.51 |
| Sept. 16 | 64.7 | 63.52 | 1.18 | 1.9 | 0.61 |
| Sept. 21 | 64.18 | 62.7 | 1.48 | 2.8 | 0.52 |
| Sept. 26 | 62.72 | 61.64 | 1.08 | 2.9 | 0.37 |

**Table A4**: Site 8 Kc Calculations for Grapes.

| Date | Maximum soil water | Minimum soil water | Water Use | ETo | Kc |
|---|---|---|---|---|---|
| July 16 | 103.88 | 101.38 | 2.5 | 5.5 | 0.45 |
| July 24 | 97.6 | 96.3 | 1.3 | 5.1 | 0.25 |
| July 26 | 96.54 | 95.52 | 1.02 | 5.1 | 0.20 |
| July 29 | 96.54 | 95.12 | 1.42 | 4.8 | 0.30 |
| Aug. 4 | 97.9 | 94.96 | 2.94 | 5.9 | 0.50 |
| Aug. 15 | 83.16 | 81.78 | 1.38 | 4.3 | 0.32 |
| Aug. 26 | 74.56 | 71.48 | 3.08 | 2.7 | 1.14 |
| Aug. 30 | 77.08 | 95.92 | 1.16 | 3.8 | 0.31 |
| Sept. 1 | 75.68 | 72.66 | 3.02 | 3.2 | 0.93 |
| Sept. 4 | 102.12 | 100.98 | 1.14 | 2.0 | 0.56 |
| Sept. 10 | 94.4 | 91.62 | 2.78 | 3.2 | 0.86 |
| Sept. 15 | 101.78 | 100.48 | 1.3 | 2.1 | 0.63 |
| Sept. 21 | 104.52 | 103.22 | 1.3 | 2.8 | 0.46 |
| Sept. 25 | 103.24 | 101.5 | 1.74 | 2.8 | 0.63 |

**Table A5**: Site 11 Kc values for Peaches

| Date | Maximum soil water | Minimum soil water | Water Use | ETo | Kc |
|---|---|---|---|---|---|
| July 11 | 51.48 | 50.02 | 1.46 | 4.8 | 0.30 |
| July 13 | 59.28 | 57.24 | 2.04 | 6.0 | 0.34 |
| July 16 | 58.46 | 55.80 | 2.66 | 5.5 | 0.48 |
| July 21 | 49.98 | 49.32 | 0.66 | 4.6 | 0.14 |
| July 24 | 54.70 | 52.18 | 2.52 | 5.1 | 0.49 |
| July 29 | 54.52 | 51.68 | 2.84 | 4.8 | 0.59 |
| Aug. 6 | 61.22 | 57.56 | 3.66 | 5.2 | 0.70 |
| Aug. 15 | 46.18 | 44.96 | 1.22 | 4.3 | 0.28 |
| Aug. 20 | 45.66 | 44.58 | 1.08 | 1.5 | 0.72 |
| Aug. 26 | 41.24 | 40.52 | 0.72 | 2.7 | 0.27 |
| Aug. 30 | 44.04 | 42.86 | 1.18 | 3.8 | 0.31 |
| Sept. 4 | 53.83 | 52.88 | 0.95 | 2.0 | 0.47 |
| Sept. 10 | 50.82 | 49.00 | 1.82 | 3.8 | 0.48 |
| Sept. 15 | 61.06 | 58.86 | 2.20 | 2.1 | 1.05 |
| Sept. 20 | 67.00 | 63.99 | 3.34 | 2.1 | 1.59 |
| Sept. 26 | 61.74 | 60.24 | 1.50 | 2.9 | 0.52 |

| | | | | | |
|---|---|---|---|---|---|
| Sept. 29 | 72.60 | 67.96 | 4.64 | 2.3 | 2.02 |

**Table A6**: Site 17 Kc values for Grapes

| Date | Maximum soil water | Minimum soil water | Water Use | ETo | Kc |
|---|---|---|---|---|---|
| July 11 | 75.04 | 72.76 | 2.28 | 4.8 | 0.47 |
| July 14 | 80.34 | 77.80 | 2.54 | 5.5 | 0.46 |
| July 16 | 81.26 | 78.28 | 2.98 | 5.5 | 0.54 |
| July 24 | 74.86 | 72.46 | 2.40 | 5.1 | 0.47 |
| July 29 | 71.76 | 69.76 | 2.00 | 4.8 | 0.42 |
| Aug. 4 | 75.48 | 70.28 | 5.20 | 5.9 | 0.89 |
| Aug. 15 | 54.5 | 53.48 | 1.02 | 4.3 | 0.24 |
| Aug. 20 | 51.56 | 50.46 | 1.10 | 1.5 | 0.73 |
| Aug. 24 | 49.80 | 48.62 | 1.18 | 2.8 | 0.43 |
| Aug. 26 | 50.06 | 48.80 | 1.26 | 2.7 | 0.47 |
| Aug. 30 | 52.48 | 51.00 | 1.48 | 3.8 | 0.39 |
| Sept. 4 | 77.36 | 73.38 | 3.98 | 2.0 | 1.96 |
| Sept. 10 | 66.18 | 64.10 | 2.08 | 3.8 | 0.55 |
| Sept. 14 | 71.26 | 69.88 | 1.38 | 1.4 | 1.02 |
| Sept. 16 | 70.02 | 68.60 | 1.42 | 1.9 | 0.73 |
| Sept. 21 | 73.60 | 71.18 | 2.42 | 2.8 | 0.86 |
| Sept. 26 | 70.14 | 68.36 | 1.78 | 2.9 | 0.62 |

**Table A7:** Determination of daily effective precipitation for Site 1

| Date | Gross Precipitation (GP) (mm) | Gross Precipitation – 5mm (GP-5) (mm) | Difference in soil moisture* (mm) | Percentage of Effective precipitation[+] |
|---|---|---|---|---|
| July 10 | 20.8 | 15.8 | 8.14 | 51.5 |
| July 12 | 26.4 | 21.4 | 10.8 | 50.5 |
| July 15 | 17.8 | 12.8 | 8.44 | 65.9 |
| July 20 | 13.4 | 8.4 | 5.56 | 66.2 |
| July 22 | 29.2 | 24.2 | 20.44 | 84.5 |
| July 28 | 5.4 | 0.4 | 3.29 | 100.0 |
| Aug. 3 | 14.0 | 9.0 | 7.46 | 82.9 |
| Aug. 14 | 6.2 | 1.2 | 3.24 | 100.0 |
| Aug. 29 | 6.2 | 1.2 | 5.16 | 100.0 |
| Sept. 2 | 27.8 | 22.8 | 18.62 | 81.7 |
| Sept. 9 | 5.2 | 0.2 | 2.71 | 100.0 |
| Sept. 12 | 9.6 | 4.6 | 2.86 | 62.2 |
| Sept. 13 | 5.8 | 0.8 | 3.17 | 100.0 |
| Sept. 18 | 15.6 | 10.6 | 14.09 | 100.0 |
| Sept. 19 | 5.4 | 0.4 | 3.80 | 100.0 |
| | | | **Average** | **83.0%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.
+ In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A8:** Determination of daily effective precipitation for Site 2

| Date | Gross Precipitation (GP) (mm) | Gross Precipitation – 5mm (GP-5) (mm) | Difference in soil moisture* (mm) | Percentage of Effective precipitation+ |
|---|---|---|---|---|
| July 2 | 6.6 | 1.6 | 0.92 | 57.5 |
| July 10 | 18.4 | 13.4 | 5.62 | 41.9 |
| July 12 | 29.8 | 24.8 | 8.10 | 32.7 |
| July 15 | 12.2 | 7.2 | 3.44 | 47.8 |
| July 20 | 13.2 | 8.2 | 5.34 | 65.1 |
| July 22 | 10.4 | 5.4 | 6.5 | 100.0 |
| July 28 | 6.0 | 1.0 | 1.11 | 100.0 |
| Aug. 3 | 12.4 | 7.4 | 5.88 | 79.5 |
| Aug. 14 | 6.6 | 1.6 | 0.76 | 47.5 |
| Aug. 29 | 7.0 | 2.0 | 3.00 | 100.0 |
| Sept. 2 | 28.0 | 23.0 | 13.54 | 58.9 |
| Sept. 3 | 5.8 | 0.8 | 0.32 | 40.0 |
| Sept. 12 | 10.0 | 5.0 | 3.92 | 78.4 |
| Sept. 13 | 6.0 | 1.0 | 2.82 | 100.0 |
| Sept. 18 | 14.4 | 9.4 | 4.5 | 47.9 |
| Sept. 19 | 7.0 | 2.0 | 2.12 | 100.0 |
| Sept. 23 | 5.8 | 0.8 | 1.66 | 100.0 |
| Sept. 27 | 5.6 | 0.6 | 0.72 | 100.0 |
| Sept. 28 | 17.2 | 12.2 | 7.24 | 59.3 |
| | | | **Average** | **71.4%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.
+ In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A9:** Determination of daily effective precipitation for Site 5

| Date | Gross Precipitation (GP) (mm) | Gross Precipitation – 5mm (GP-5) (mm) | Difference in soil moisture* (mm) | Percentage of Effective precipitation+ |
|---|---|---|---|---|
| July 2 | 6.6 | 1.6 | 4.17 | 100.0 |
| July 10 | 18.4 | 13.4 | 38.38 | 100.0 |
| July 12 | 29.8 | 24.8 | 11.98 | 48.3 |

| | | | | |
|---|---|---|---|---|
| July 15 | 12.2 | 7.2 | 6.04 | 83.9 |
| July 20 | 13.2 | 8.2 | 37.32 | 100.0 |
| July 22 | 10.4 | 5.4 | 3.62 | 67.0 |
| July 28 | 6.0 | 1.0 | 8.14 | 100.0 |
| Aug. 3 | 12.4 | 7.4 | 34.56 | 100.0 |
| Aug. 14 | 6.6 | 1.6 | 6.01 | 100.0 |
| Aug. 29 | 7.0 | 2.0 | 4.00 | 100.0 |
| Sept. 2 | 28.0 | 23.0 | 44.14 | 100.0 |
| Sept. 3 | 5.8 | 0.8 | 7.99 | 100.0 |
| Sept. 12 | 10.0 | 5.0 | 12.40 | 100.0 |
| Sept. 13 | 6.0 | 1.0 | 6.08 | 100.0 |
| Sept. 18 | 14.4 | 9.4 | 21.63 | 100.0 |
| Sept. 19 | 7.0 | 2.0 | 11.38 | 100.0 |
| Sept. 23 | 5.8 | 0.8 | 7.48 | 100.0 |
| Sept. 27 | 5.6 | 0.6 | 7.70 | 100.0 |
| Sept. 28 | 17.2 | 12.2 | 4.56 | 37.4 |
| | | | **Average** | **91.4%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.

+ In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A10:** Determination of daily effective precipitation for Site 8

| Date | Gross Precipitation (GP) (mm) | Gross Precipitation – 5mm (GP-5) (mm) | Difference in soil moisture* (mm) | Percentage of Effective precipitation+ |
|---|---|---|---|---|
| July 15 | 10.0 | 5.0 | 1.22 | 24.4 |
| July 20 | 12.0 | 7.0 | 5.60 | 80.0 |
| July 22 | 5.8 | 0.8 | 0.54 | 67.5 |
| July 28 | 7.2 | 2.2 | 2.1 | 95.5 |
| Aug. 3 | 16.0 | 11.0 | 8.28 | 75.3 |
| Aug. 14 | 7.0 | 2.0 | 5.56 | 100.0 |
| Aug. 29 | 6.8 | 1.8 | 5.68 | 100.0 |
| Sept. 2 | 34.4 | 29.4 | 36.93 | 100.0 |
| Sept. 12 | 9.2 | 4.2 | 10.09 | 100.0 |
| Sept. 13 | 7.4 | 2.4 | 4.45 | 100.0 |
| Sept. 18 | 17.8 | 12.8 | 12.93 | 100.0 |
| Sept. 19 | 5.2 | 0.2 | 6.48 | 100.0 |
| Sept. 23 | 6.2 | 1.2 | 1.93 | 100.0 |
| Sept. 27 | 9.0 | 4.0 | 3.42 | 85.5 |
| Sept. 28 | 15.4 | 10.4 | 10.65 | 100.0 |
| | | | **Average** | **88.5%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.
[+] In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A11:** Determination of daily effective precipitation for Site 11

| Date | Gross Precipitation (GP) | Gross Precipitation – 5mm (GP-5) | Difference in soil moisture* | Percentage of Effective precipitation[+] |
|---|---|---|---|---|
| July 10 | 10.2 | 5.2 | 3.34 | 64.2 |
| July 12 | 30.4 | 25.4 | 9.44 | 37.2 |
| July 15 | 10.8 | 5.8 | 5.92 | 100.0 |
| July 22 | 5.6 | 0.6 | 0.28 | 46.7 |
| July 23 | 11.0 | 6.0 | 4.92 | 82.0 |
| July 28 | 7.6 | 2.6 | 6.06 | 100.0 |
| Aug. 2 | 10.6 | 5.6 | 4.76 | 85.0 |
| Aug. 3 | 14.4 | 9.4 | 7.90 | 84.0 |
| Aug. 4 | 23.6 | 18.6 | 19.83 | 100.0 |
| Aug. 19 | 13.4 | 8.4 | 4.50 | 53.6 |
| Aug. 27 | 5.4 | 0.4 | 0.98 | 100.0 |
| Aug. 29 | 8.8 | 3.8 | 2.44 | 64.2 |
| Sept. 2 | 36.2 | 31.2 | 12.02 | 38.5 |
| Sept. 12 | 11.4 | 6.4 | 0.52 | 8.1 |
| Sept. 13 | 21.8 | 16.8 | 12.42 | 73.9 |
| Sept. 18 | 19.2 | 14.2 | 13.46 | 94.8 |
| Sept. 19 | 7.6 | 2.6 | 6.01 | 100.0 |
| Sept. 23 | 8.0 | 3.0 | 4.69 | 100.0 |
| Sept. 28 | 29.4 | 24.4 | 15.12 | 62.0 |
| | | | **Average** | **73.4%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.
[+] In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A12:** Determination of daily effective precipitation for Site 17

| Date | Gross Precipitation (GP) (mm) | Gross Precipitation – 5mm (GP-5) (mm) | Difference in soil moisture* (mm) | Percentage of Effective precipitation[+] |
|---|---|---|---|---|
| July 10 | 15.0 | 10.0 | 10.24 | 100.0 |
| July 12 | 32.6 | 27.6 | 13.2 | 47.8 |
| July 15 | 14.2 | 9.2 | 7.68 | 83.5 |
| July 20 | 6.0 | 1.0 | 0.68 | 68.0 |

| | | | | |
|---|---|---|---|---|
| July 22 | 10.4 | 5.4 | 5.83 | 100.0 |
| July 28 | 15.6 | 10.6 | 4.12 | 38.9 |
| Aug. 2 | 6.6 | 1.6 | 2.09 | 100.0 |
| Aug. 3 | 19.4 | 14.4 | 11.9 | 82.8 |
| Aug. 14 | 5.6 | 0.6 | 1.19 | 100.0 |
| Aug. 19 | 7.8 | 2.8 | 1.06 | 37.9 |
| Aug. 25 | 9.4 | 4.4 | 1.30 | 29.6 |
| Aug. 29 | 10.2 | 5.2 | 3.80 | 73.1 |
| Sept. 2 | 36.4 | 31.4 | 23.96 | 76.3 |
| Sept. 3 | 10.6 | 5.6 | 4.40 | 78.6 |
| Sept. 12 | 11.4 | 6.4 | 1.40 | 21.9 |
| Sept. 13 | 10.8 | 5.8 | 9.41 | 100.0 |
| Sept. 18 | 18.6 | 13.6 | 5.50 | 40.4 |
| Sept. 19 | 9.2 | 4.2 | 8.14 | 100.0 |
| Sept 27 | 5.4 | 0.4 | 0.08 | 20.0 |
| Sept. 28 | 27.8 | 22.8 | 12.96 | 56.8 |
| | | | **Average** | **67.8%** |

*The difference between the soil moisture prior to the rainfall and the maximum soil moisture resulting from the rainfall event.

[+] In the analysis of the average efficiency, if the percentage of effective precipitation was greater than 100%, a value of 100% was used in the average calculation as these values are likely the result of heterogeneous patterns of rainfall runoff.

**Table A13:** Historical effective precipitation

| | **May** | **June** | **July** | **August** | **September** |
|---|---|---|---|---|---|
| 1970 | 18.6 | 35.7 | 26.0 | 53.9 | 39.4 |
| 1971 | 10.6 | 35.7 | 45.4 | 46.5 | 46.9 |
| 1972 | 31.0 | 31.5 | 13.7 | 13.7 | 19.1 |
| 1973 | 24.0 | 40.3 | 14.4 | 0 | 20.2 |
| 1974 | 41.0 | 32.6 | 21.4 | 2.7 | 17.5 |
| 1975 | 23.2 | 36.1 | 24.9 | 36.7 | 17.4 |
| 1976 | 48.8 | 34.5 | 23.4 | 28.3 | 34.7 |
| 1977 | 21.0 | 22.4 | 25.6 | 83.4 | 110.9 |
| 1978 | 8.7 | 26.5 | 13.0 | 52.1 | 102.9 |
| 1979 | 34.6 | 26.0 | 44.8 | 30.2 | 46.7 |
| 1980 | 9.70 | 60.2 | 27.2 | 5.7 | 56.1 |
| 1981 | 39.7 | 50.8 | 86.4 | 20.5 | 52.1 |
| 1982 | 28.1 | 48.3 | 23.5 | 44.1 | 36.7 |
| 1983 | 38.6 | 43.8 | 20.8 | 36.7 | 17.5 |
| 1984 | 29.1 | 109.3 | 8.4 | 52.1 | 84.2 |
| 1985 | 7.5 | 22.7 | 22.7 | 46.9 | 4.8 |
| 1986 | 32.1 | 30.8 | 74.0 | 6.2 | 61.6 |
| 1987 | 11.0 | 28.3 | 36.7 | 81.3 | 38.3 |
| 1988 | 6.4 | 0.6 | 81.1 | 24.3 | 20.8 |
| 1989 | 40.0 | 32.7 | 34.3 | 9.7 | 65.3 |

| | | | | | |
|---|---|---|---|---|---|
| 1990 | 52.4 | 19.2 | 28.7 | 51.4 | 17.4 |
| 1994 | 30.5 | 55.6 | 69.1 | 31.4 | 27.8 |
| 1995 | 12.7 | 13.2 | 21.3 | 31.1 | 10.0 |
| 1996 | 65.1 | 36.0 | 42.6 | 41.1 | 115.3 |
| 1997 | 16.4 | 34.6 | 5.9 | 27.8 | 26.2 |
| 1998 | 21.1 | 17.8 | 43.5 | 3.5 | 5.4 |
| 1999 | 14.5 | 8.6 | 52.2 | 14.0 | 61.6 |
| 2000 | 45.9 | 91.0 | 30.5 | 46.2 | 58.8 |
| 2001 | 48.9 | 11.3 | 1.3 | 47.5 | 21.3 |
| 2002 | 40.3 | 24.8 | 27.3 | 5.9 | 33.2 |
| **Average** | 28.4 | 35.4 | 33.0 | 32.5 | 42.3 |
| **10-year return** | 9.6 | 13.0 | 12.6 | 5.5 | 16.7 |