A SunCam online continuing education course

Green Irrigation Fundamentals

Balancing Aquifer Recharge and Withdrawal

by

Nicolas E. Andreyev, P.E.

Forward

The amount of technical effort to regulate water use for irrigation and the excessive cost of various water management and water conservation programs developed throughout the state of Florida and other similar areas, begs the question of why we can't develop a scientifically prudent approach to balance the water withdrawal with the water recharge in a particular area, resulting in a zero net impact on water resources. This introduction to a balanced irrigation water demand methodology is presented specifically for Florida, USA. However, the methodology is applicable to anywhere in the world where similar water management challenges exist and where conservation of water resources is important.

This methodology is presented to allow for a systematic approach to evaluate and determine the optimum irrigation water demand for a particular house, a residential development or commercial development or any other project where impervious surfaces are created and the land use is changed to reduce evapotranspiration water losses. For areas where the stormwater runoff is retained or reused within the same drainage basin or aquifer basin, the use of balanced irrigation water would essentially self-regulate groundwater withdrawal and aquifer recharge without the need to continuously perform costly analysis of the effects of withdrawals. The approach is relatively simple: if the amount of irrigation water used is equal to the amount of additional water created by the improvements to recharge the aquifer, then the net effect is zero (no impact).

Objective

The primary objective of this short course is to introduce a methodology that can be used by individual home owners, developers, engineers, planners, regulators and any other water managers who are interested in the conservation of water and a systematic application of water use restrictions based on scientific principles. The intent of the author is to provide an introduction to the basic concept of a water balanced approach to determine the amount of optimum irrigation water needed and the hope that this will lead to meaningful discussions as to the merit of this simple approach to minimize further impacts of groundwater withdrawals for irrigation. The approach has been evaluated and permitted at the various water management districts and might become an industry standard with all of the merits of its simplicity and cost saving benefits.

Once this concept of balanced irrigation water demand is introduced in its basic form, future discussion may lead to the next level of research and analysis to expand the water balance to the more complex parameters, such as long term volumetric water balance, downstream base flow matching, shallow aquifer storage and recovery, effects of irrigation itself and many other parameters.

Background

The author has utilized this approach of balanced water uses for various developments throughout Florida, optimizing reuse of stormwater and balancing the aquifer withdrawal and recharge, as well as, balancing surface discharge from proposed developments. One of the better examples for this approach is the large development in Central Florida, "The Villages". This concept has been fully integrated into the original design and is now implemented in the operation of the potable water supply and irrigation water supply. At The Villages, 100% of all water is retained on-site and either reused for irrigation or is allowed to recharge into the aquifer.

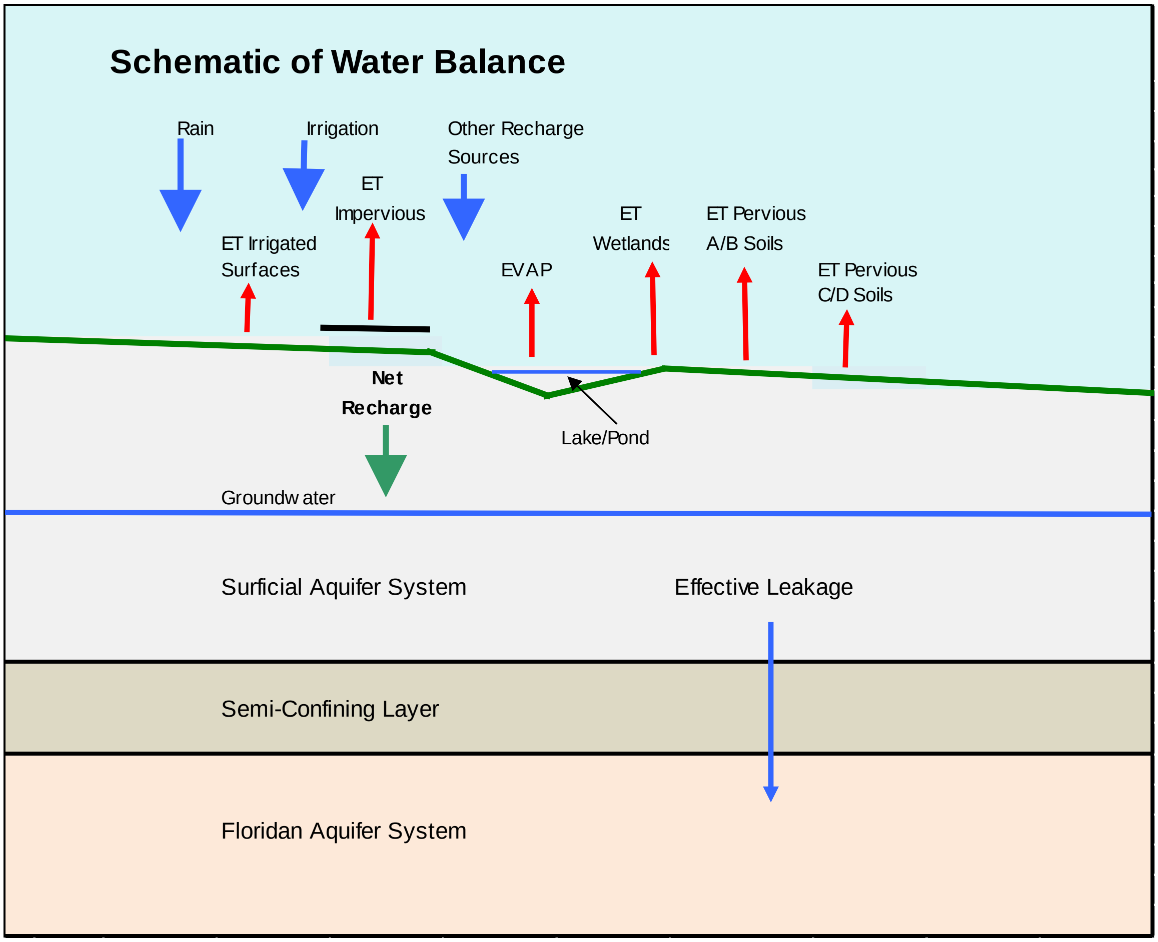
This balanced irrigation water demand concept can be extended further into smaller projects and even for individual houses as demonstrated herein. Once this concept is understood, the author believes that this simple and common sense approach will be embraced by all, technical and non-technical people alike.

Basic Concept of Balanced Irrigation Water Demand

Water use for irrigation, and more specifically groundwater use in Florida, has been recognized as the leading cause of over-pumping of the aquifer systems in Florida. The potable water use also causes over-pumping concerns, but its use is much more difficult to reduce or eliminate. Therefore, the low hanging fruit in the reduction of groundwater use is to reduce or eliminate irrigation demand. To achieve a meaningful reduction of irrigation water uses, it is necessary to understand the various components of the water cycle that affects a true loss of water. The following 3 conditions of surface and aquifer settings are typical in Florida and perhaps in many parts of the world:

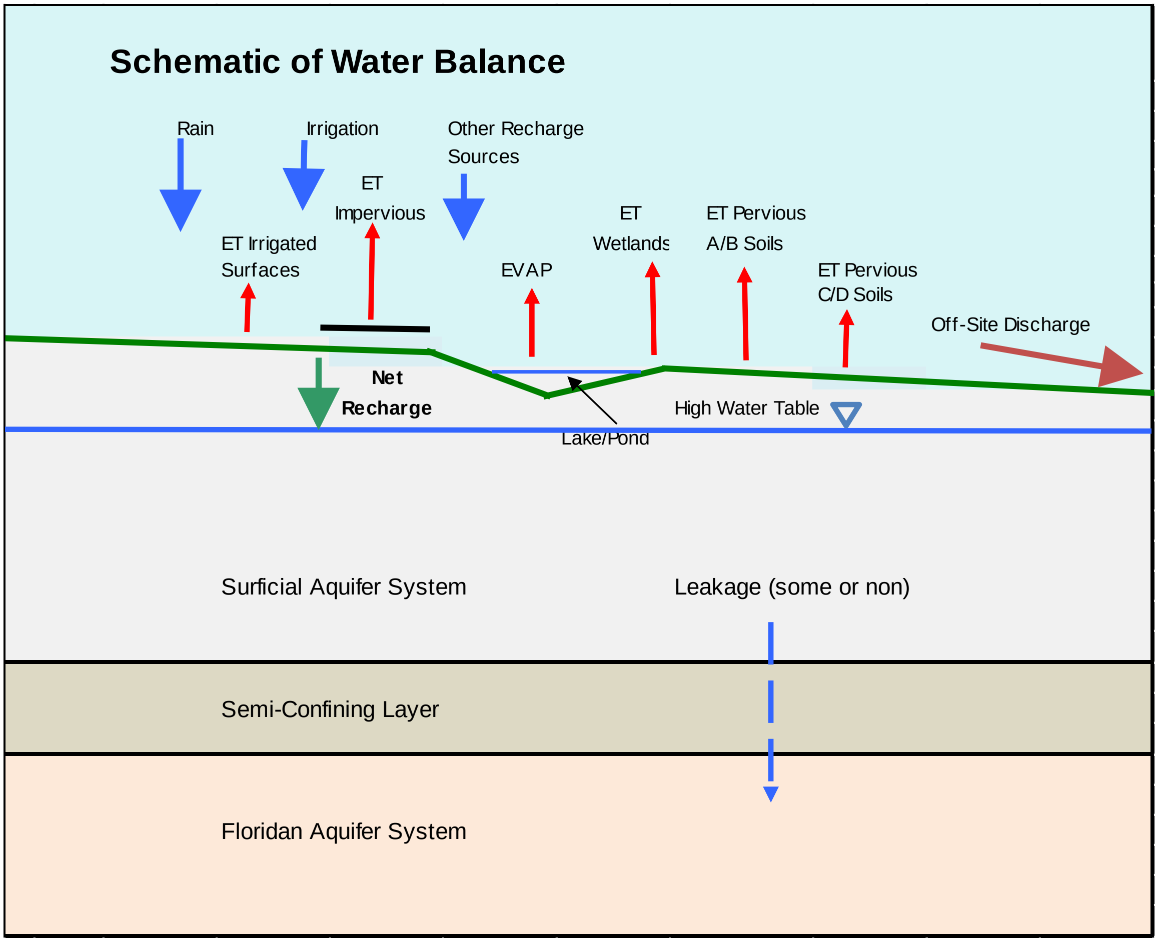
1. **Closed Drainage Basins with Unconfined Aquifer**: This is a typical setting in large portions of north, central and southwestern Florida (e.g. "The Villages"). This is a setting where most of the rain infiltrates directly into the shallow aquifer, where surface runoff from larger storms flows to lakes and/or depressions without direct outflow beyond the boundaries of the drainage basin. All water introduced to this area is either lost to evaporation and evapotranspiration or infiltrates back

into the shallow aquifer with subsequent leakage into the deeper Floridan aquifer system. These internally drained basins are ideal and are the simplest areas to implement a balanced irrigation water demand. The following schematic shows the basic components of the water cycle in the context of this water balance concept:



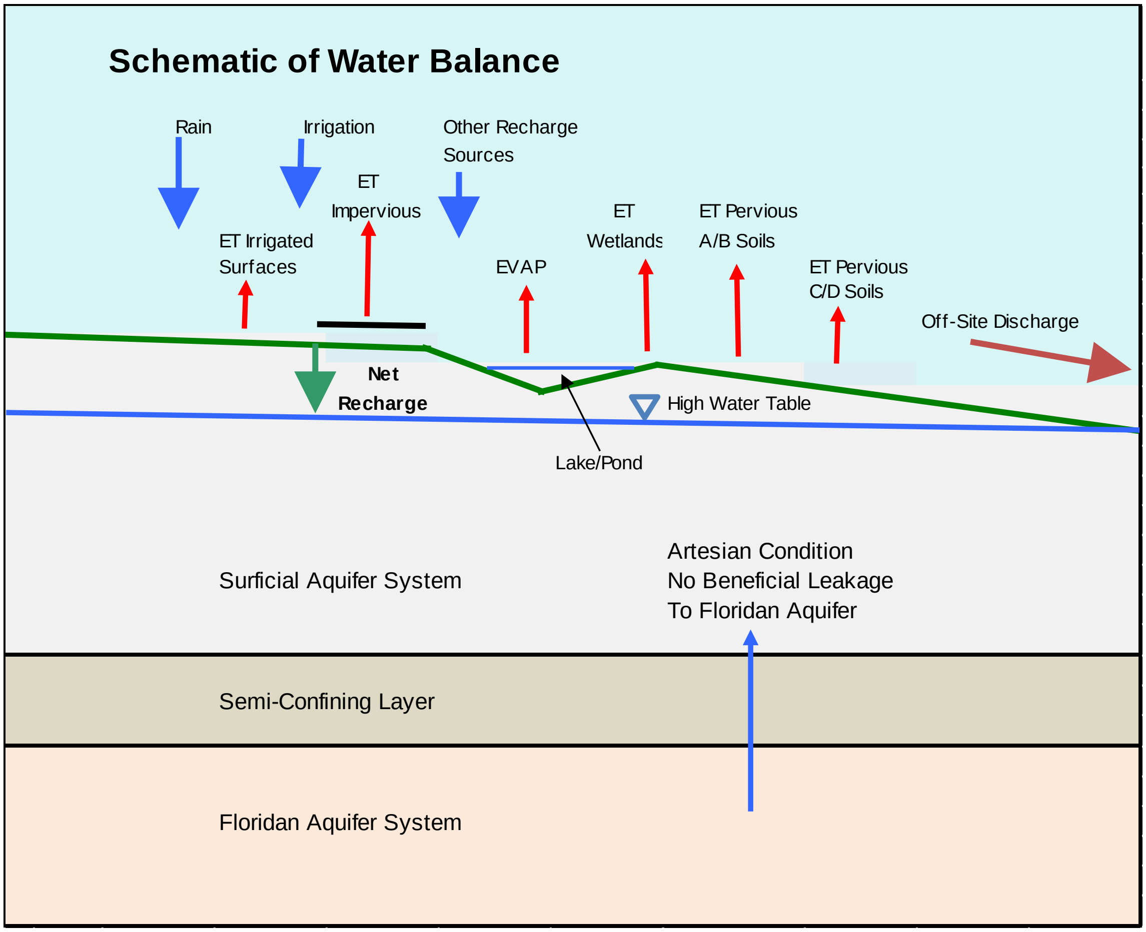
2. **Drainage Basins with Surface Discharge and Shallow Water Table**: This is also a very typical setting in large portions of Florida. This setting will generally consist of areas locally known as “pine flatwoods or a flatwood forest”. These areas also have a shallow aquifer system underlain by the Floridan aquifer system. However, due to the shallow water table and low vertical leakage conditions, the runoff water is partially retained within the drainage basin but some or most of the runoff water does discharge beyond the drainage basin. Often the discharges feed various drainage ways, creeks and rivers that ultimately discharge into the ocean. Any recharge in these areas will benefit the

shallow aquifer, but may or may not contribute beneficial recharge to the underlying Floridan aquifer.



3. **Drainage Basins with Aquifer Discharge Conditions**: This setting is typical along most coastline communities in Florida and especially in the southeast and southwestern portions of Florida. The general setting will have a shallow aquifer system that can produce moderate amount of potable and irrigation water. The deeper portions of the shallow aquifer, and the majority of the Floridan aquifer systems in this type of setting, occur under artesian conditions (the pressure of the aquifer is above the ground surface). Similar to Condition 2 above, the surface runoff can be partially retained within the drainage basin, but most of the runoff typically flows to canals, creeks and rivers and discharges into the ocean or inter-coastal waterways. The shallow aquifer has a potential for beneficial recharge, however, the Floridan aquifer has no possibility for beneficial recharge.

The analysis presented in this introductory course has a very limited use under this type of aquifer setting.



Water Sources

The water sources needed to be identified and quantified for the balanced irrigation water demand analysis are relatively easy. Typically, these consist of primarily the rainfall in the area and reliable weather stations that collect the rainfall data on a daily, hourly or a continuous basis. Furthermore, most areas in Florida have radar rainfall data that can be downloaded for any point, area or region. Other sources of water that can affect the water balance analysis include irrigation (if irrigation water is from an off-site source), septic tank discharge (if potable water is from an off-site source), and surface inflow from off-site runoff. However, for the purpose of this introductory course to the balanced irrigation water demand, the methodology presented herein will be limited to the basic components of water sources being just rainfall, with the water losses being the evaporation and evapotranspiration from various land uses or land surface types.

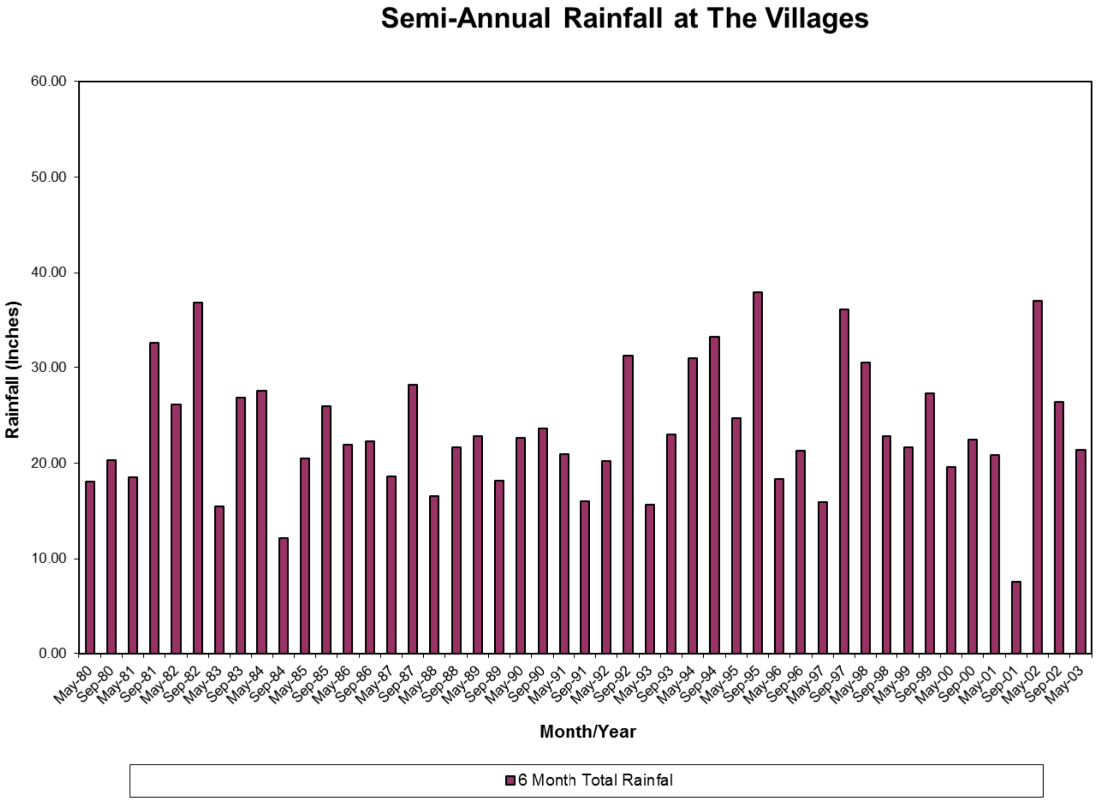
The following is a sample of rainfall data and graphs that can be obtained from various sources, including the National Oceanic and Atmospheric Administration (NOAA) stations, the National Climatic Data Center (NCDC), state and county government agencies (Department of Environmental Protection, Water Management Districts, Engineering Departments, Water Operators, and others) and private companies providing meteorological data. Private companies, and some of the government offices, sometimes charge a fee to provide the data. However, most of the rainfall data can be obtained free of charge:

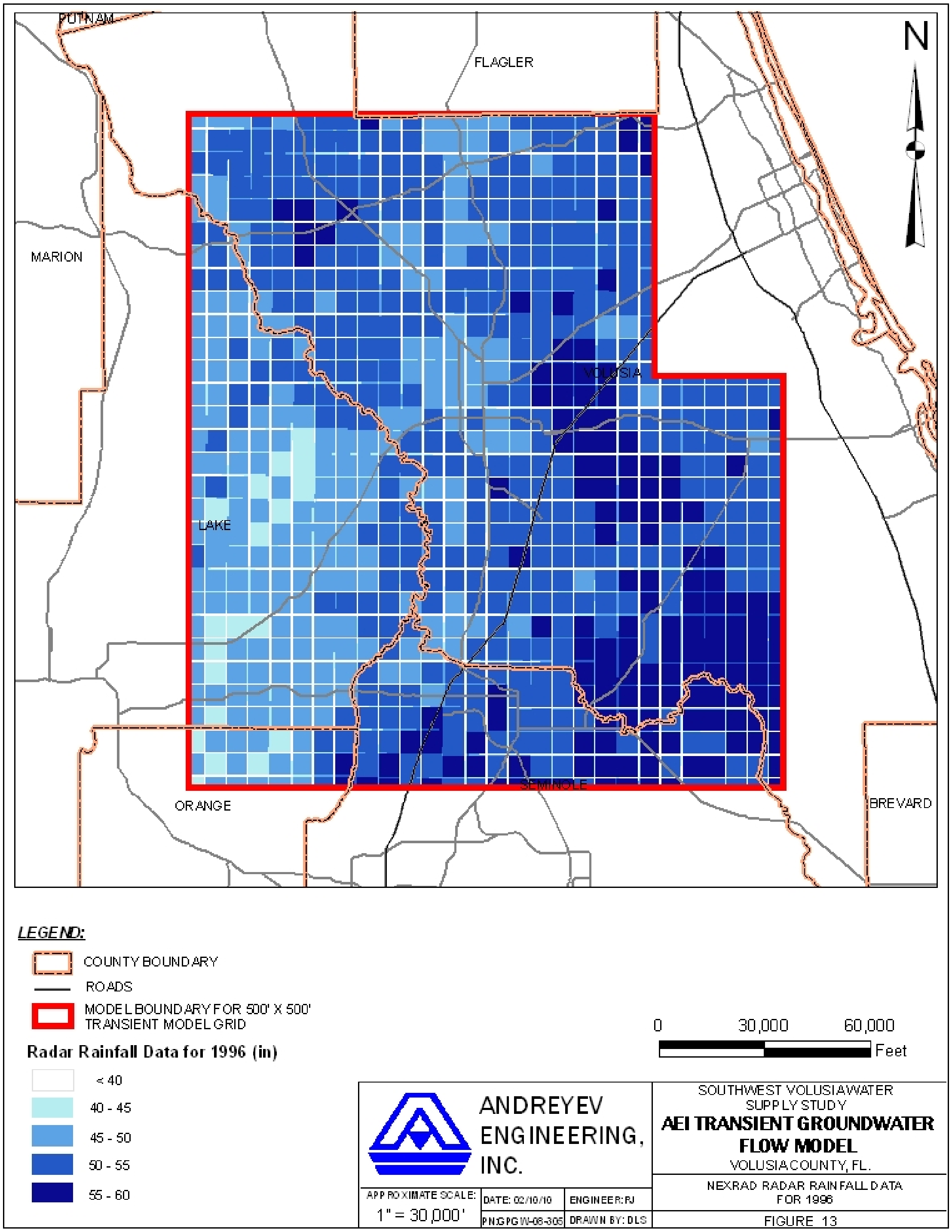
Lisbon, Florida NOAA Station: Daily Rainfall 1973-2006											
1973			**1974**			**1975**			**1976**		
Date	**inx100**	**in**	**Date**	**inx100**	**in**	**Date**	**inx100**	**in**	**Date**	**inx100**	**in**
1/1/1973	0	0	1/1/1974	0	0	1/1/1975	0	0	1/1/1976	0	0
1/2/1973	0	0	1/2/1974	0	0	1/2/1975	0	0	1/2/1976	0	0
1/3/1973	0	0	1/3/1974	1	0.01	1/3/1975	0	0	1/3/1976	0	0
1/4/1973	7	0.07	1/4/1974	0	0	1/4/1975	0	0	1/4/1976	1	0.01
1/5/1973	0	0	1/5/1974	0	0	1/5/1975	0	0	1/5/1976	0	0
1/6/1973	0	0	1/6/1974	0	0	1/6/1975	60	0.6	1/6/1976	97	0.97
1/7/1973	0	0	1/7/1974	0	0	1/7/1975	0	0	1/7/1976	0	0
1/8/1973	0	0	1/8/1974	0	0	1/8/1975	0	0	1/8/1976	34	0.34
1/9/1973	0	0	1/9/1974	0	0	1/9/1975	0	0	1/9/1976	0	0
1/10/1973	17	0.17	1/10/1974	0	0	1/10/1975	0	0	1/10/1976	0	0
1/11/1973	135	1.35	1/11/1974	0	0	1/11/1975	61	0.61	1/11/1976	0	0
1/12/1973	73	0.73	1/12/1974	0	0	1/12/1975	2	0.02	1/12/1976	0	0
1/13/1973	0	0	1/13/1974	0	0	1/13/1975	33	0.33	1/13/1976	0	0
1/14/1973	0	0	1/14/1974	0	0	1/14/1975	0	0	1/14/1976	0	0
1/15/1973	0	0	1/15/1974	0	0	1/15/1975	0	0	1/15/1976	0	0
1/16/1973	0	0	1/16/1974	0	0	1/16/1975	0	0	1/16/1976	0	0
1/17/1973	0	0	1/17/1974	0	0	1/17/1975	0	0	1/17/1976	2	0.02
1/18/1973	0	0	1/18/1974	0	0	1/18/1975	0	0	1/18/1976	0	0
1/19/1973	0	0	1/19/1974	0	0	1/19/1975	0	0	1/19/1976	0	0
1/20/1973	0	0	1/20/1974	0	0	1/20/1975	6	0.06	1/20/1976	0	0
1/21/1973	0	0	1/21/1974	0	0	1/21/1975	0	0	1/21/1976	0	0
1/22/1973	114	1.14	1/22/1974	0	0	1/22/1975	0	0	1/22/1976	0	0
1/23/1973	18	0.18	1/23/1974	0	0	1/23/1975	0	0	1/23/1976	0	0
1/24/1973	1	0.01	1/24/1974	0	0	1/24/1975	0	0	1/24/1976	0	0
1/25/1973	0	0	1/25/1974	0	0	1/25/1975	52	0.52	1/25/1976	0	0
1/26/1973	0	0	1/26/1974	0	0	1/26/1975	4	0.04	1/26/1976	0	0
1/27/1973	13	0.13	1/27/1974	0	0	1/27/1975	0	0	1/27/1976	58	0.58
1/28/1973	74	0.74	1/28/1974	0	0	1/28/1975	0	0	1/28/1976	12	0.12
1/29/1973	0	0	1/29/1974	0	0	1/29/1975	0	0	1/29/1976	0	0
1/30/1973	0	0	1/30/1974	0	0	1/30/1975	0	0	1/30/1976	0	0
1/31/1973	0	0	1/31/1974	9	0.09	1/31/1975	0	0	1/31/1976	0	0
2/1/1973	1	0.01	2/1/1974	0	0	2/1/1975	0	0	2/1/1976	64	0.64
2/2/1973	53	0.53	2/2/1974	0	0	2/2/1975	0	0	2/2/1976	0	0
2/3/1973	9	0.09	2/3/1974	0	0	2/3/1975	0	0	2/3/1976	0	0
2/4/1973	0	0	2/4/1974	2	0.02	2/4/1975	0	0	2/4/1976	0	0
2/5/1973	0	0	2/5/1974	0	0	2/5/1975	72	0.72	2/5/1976	0	0
2/6/1973	0	0	2/6/1974	0	0	2/6/1975	15	0.15	2/6/1976	0	0
2/7/1973	0	0	2/7/1974	0	0	2/7/1975	73	0.73	2/7/1976	0	0
2/8/1973	0	0	2/8/1974	3	0.03	2/8/1975	0	0	2/8/1976	0	0
2/9/1973	0	0	2/9/1974	0	0	2/9/1975	0	0	2/9/1976	0	0
2/10/1973	147	1.47	2/10/1974	0	0	2/10/1975	0	0	2/10/1976	0	0
2/11/1973	0	0	2/11/1974	0	0	2/11/1975	2	0.02	2/11/1976	0	0
2/12/1973	0	0	2/12/1974	0	0	2/12/1975	27	0.27	2/12/1976	0	0

Clermont, Florida NOAA Station 7, Monthly Rainfall (1940-1995)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1940	2.3	3.53	3.67	2.07	1.1	7.02	9.09	5.98	4.57	0.04	0.16	8.3	47.83
1941	5.31	4.76	3.39	5.4	1.09	6.62	9.42	0.97	3.8	3.54	4.46	3.9	52.66
1942	3.03	2.94	7.35	2.73	3.26	10.58	3.48	6.16	3.33	0.39	0.12	3.74	47.11
1943	0.93	0.55	3.9	2.2	3.75	3.53	14.51	9.5	8.12	1.07	0.48	0.66	49.2
1944	2.68	0.27	4.46	2.22	2.46	7.86	16.58	4.5	5.41	9.33	0.34	0	56.11
1945	2.76	0.17	0.54	0.59	1.55	16.5	9.85	7.82	8.33	0.57	0	0	48.68
1946	0	3.88	2.65	1	3.09	4.22	9.14	8.06	3.48	1.55	2.83	0.45	40.35
1947	0.48	4.27	6.67	4.91	2.66	8.04	6.75	6.07	8.9	2.93	1.56	0.91	54.15
1948	5.86	0.33	4.19	2.94	0.65	1.7	13	7.6	5.32	2.03	1.32	1.57	46.51
1949	0.25	0.85	0.8	2.67	0.92	10.32	6.8	14.26	3.26	1.87	1.23	2.39	45.62
1950	0.05	0.29	3.85	4.36	4.07	4.28	4.72	6.41	15.42	6.85	0.2	4.29	54.79
1951	0.67	0	1.35	6.92	2.93	7.06	7.71	4.69	9.42	1.65	4.72	2	49.12
1952	1.06	5.32	4.18	2.25	1.95	3.99	3.6	7.19	4.67	6.02	1.08	0.7	42.01
1953	2.43	2.22	4.53	6.81	1.57	9.26	10.16	12.06	6.56	2.47	3.59	5.21	66.87
1954	0.85	2.12	1.28	1.63	1.27	6.08	8.05	3.11	4.23	3.02	2.3	1.69	35.63
1955	1.93	1.04	1.91	2.49	4.73	6.2	6.53	4.85	4.81	1.84	2.95	0.96	40.24
1956	1.72	1.71	0.15	3.47	7.89	5.22	9.92	4.6	5.1	8.64	0.51	0.29	49.22
1957	1.52	2.12	3.4	5.24	4.99	7.74	10.72	5.35	6.51	0.99	0.58	2.88	52.04
1958	4.29	4.2	7.88	4.47	1.89	5.55	13.13	6.38	2.2	6.52	1.9	3.67	62.08
1959	4.76	4.41	9.47	5.88	4.88	7.81	8.52	5.72	9.68	4.88	0.88	1.2	68.09
1960	1.25	5.47	12.95	5.29	2.5	4.38	12.5	7.09	11.38	2.24	0.14	1.08	66.27
1961	1.38	3.46	0.95	0.79	1.91	5.32	3.71	6.86	1.08	3	1.56	2.26	32.28
1962	0.88	2.55	3.56	2.79	1.2	9	4.73	5.58	4.82	3.23	1.58	0.41	40.33
1963	3.22	5.64	3.34	1.39	1.87	5.85	7.38	4.5	8.6	0.27	5.62	2.36	50.04
1964	5.91	3.76	6.24	2.11	1.83	5.39	8.36	7.9	8.12	1.22	1.22	3.09	55.15
1965	2.02	3.14	2.76	1.64	0.12	6.94	11.78	7.98	3.68	3.69	1.11	2.95	47.81
1966	4.73	4.46	1.95	2.7	4.96	9.17	3.91	10.32	11.81	1.47	0.19	0.95	56.62
1967	1.27	5.67	0.81	0.01	1.89	6.16	12.62	16.23	6.2	0.26	0.22	2.19	53.53
1968	0.75	2.24	1.36	0.29	4.73	11.54	8.1	9.93	5.28	3.89	3.74	1.54	53.39
1969	1.51	3.06	6.26	2.56	1.45	6.62	7.22	11.36	9.29	6.61	2.11	5.66	63.71
1970	4.64	4.92	4.58	0.61	3.38	7.17	5.76	4.26	7.89	2.69	0.81	1.5	48.21
1971	2.09	3.94	2.43	1.25	4.76	4.78	10.95	7.22	5.17	4.41	1.55	1.22	49.77
1972	1.24	5.26	4.43	2.52	1.7	9.9	3.35	8.14	1.62	2.9	3.41	2.2	46.67
1973	4.7	1.94	4.49	2.67	4.8	5.38	8.48	7.6	8.92	1.02	1.2	3.74	54.94
1974	0.46	1.2	3.89	0.85	4.77	12.08	7.81	4.76	7.24	0.25	0.27	1.81	45.39
1975	2.58	2.35	0.82	2.66	7.18	5.88	7.23	8.41	6.83	2.14	2.66	1.07	49.81
1976	0.58	0.25	1.11	3.2	4.98	13.71	9.75	9.78	4.91	1.69	3.44	2.56	55.96
1977	2.96	2.05	1.64	0.16	1.03	3.1	8.7	6.7	5.96	1.7	3.12	3.29	40.41
1978	2.62	5.41	2.73	0.9	7.18	10.94	9.73	2.53	2.6	1.48	0	4.67	50.79
1979	6.06	1.83	3.47	3.6	8.99	2.89	4.54	9.43	21.14	1.29	3.32	0.8	67.36
1980	2.12	1.05	2.68	3.56	6.24	4.23	7.75	3.92	3.5	1.33	3.32	0.4	40.1
1981	0.33	4.43	2.96	0	1.42	10.61	6.45	9.29	6.87	0.61	3.41	5.81	52.19
1982	2.5	2.21	6.62	4.87	5.36	5.93	7.82	4.87	6.45	5.07	1.86	0.31	53.87
1983	2.43	7.64	7.31	3.24	2.42	8.51	2.92	6.14	4.55	5.67	1.93	4.94	57.7
1984	2.12	3.01	0.92	2.76	5.64	8.64	10.09	9.35	4.13	0.26	1.52	0.31	48.75
1985	1.4	1.07	2.64	0.96	3.16	11.63	7.89	8.56	7.18	2.94	0.3	2.91	50.64
1986	9.41	1.89	3.56	0.72	0.92	8.69	5.69	8.15	4.03	1.68	1.39	2.45	48.58
1987	0	3.17	12.4	0.52	3.4	3.88	0	3.14	5.59	1.94	11.2	0.62	45.86
1988	5.2	1.72	8.17	0.39	2.7	8.81	7.15	7.88	4.8	1.66	8.56	1.85	58.89
1989	4.01	0.06	1.58	3.5	2.76	9.93	7.48	5.89	7.64	0.34	1.76	0	44.95
1990	0.41	4.16	2.11	0.95	1.07	10.67	10.03	6.43	5.03	2.23	1.29	0.2	44.58
1991	3.81	0.68	7.72	4.46	6.1	5.12	7.47	0	1.39	3.57	0.2	0.16	40.68
1992	0	4.68	3.33	3.37	2.48	10.09	4.25	13.35	3.1	4.77	2.36	0	51.78
1993	6.04	1.92	5.25	2.58	4.47	2.36	2.93	5.39	0	2.58	0.1	1.08	34.7
1994	5.77	2.1	2.48	0.8	3.72	13.37	8.76	9.53	8.7	2.25	5.07	2.93	65.48
1995	0	1.04	2.5	3.09	4.25	11.34	4.65	7.87	5.59	8.65	0.1	0.89	49.97
Avg	**2.49**	**2.76**	**3.89**	**2.57**	**3.29**	**7.49**	**7.85**	**7.10**	**6.15**	**2.81**	**2.02**	**2.05**	**50.45**

Rainlog Rainfall Report	
Date	*Rainfall*
4/20/12 0:00	0.00
4/21/12 0:00	0.09
4/22/12 0:00	0.61
4/23/12 0:00	0.00
4/24/12 0:00	0.00
4/25/12 0:00	0.00
4/26/12 0:00	0.00
4/27/12 0:00	0.00
4/28/12 0:00	0.01
4/29/12 0:00	0.00
4/30/12 0:00	0.00
5/1/12 0:00	0.00
5/2/12 0:00	0.00
5/3/12 0:00	0.00
5/4/12 0:00	0.00
5/5/12 0:00	0.00
5/6/12 0:00	0.00
5/7/12 0:00	0.45
5/8/12 0:00	0.00
5/9/12 0:00	0.08
5/10/12 0:00	0.00
5/11/12 0:00	0.00
5/12/12 0:00	0.00
5/13/12 0:00	0.00
5/14/12 0:00	0.53
5/15/12 0:00	0.00
5/16/12 0:00	0.71
5/17/12 0:00	0.02
5/18/12 0:00	0.07
5/19/12 0:00	0.01
5/20/12 0:00	0.00
5/21/12 0:00	0.00
5/22/12 0:00	0.00
5/23/12 0:00	0.00
5/24/12 0:00	0.00
5/25/12 0:00	0.00
5/26/12 0:00	0.00
5/27/12 0:00	0.01
5/28/12 0:00	0.54
5/29/12 0:00	0.24
5/30/12 0:00	0.10
5/31/12 0:00	0.00
6/1/12 0:00	1.73
6/2/12 0:00	0.00
6/3/12 0:00	0.00
6/4/12 0:00	0.01


Semi-Annual Rainfall at The Villages


PUTNAM
FLAGLER
MARION
VOLUSIA
LAKE
ORANGE
SEMINOLE
BREVARD
N
LEGEND:
COUNTY BOUNDARY
ROADS
MODEL BOUNDARY FOR 500' X 500' TRANSIENT MODEL GRID
Radar Rainfall Data for 1996 (in)
< 40
40 - 45
45 - 50
50 - 55
55 - 60
0
30,000
60,000
Feet
ANDREYEV ENGINEERING, INC.
SOUTHWEST VOLUSIA WATER SUPPLY STUDY
AEI TRANSIENT GROUNDWATER FLOW MODEL
VOLUSIA COUNTY, FL.
NEXRAD RADAR RAINFALL DATA FOR 1996
APPROXIMATE SCALE:
1" = 30,000'
DATE: 02/10/10
ENGINEER: RJ
PN:GPGW-08-305
DRAWN BY: DLS
FIGURE 13

Water Losses

Water losses are much harder to obtain for a particular project, as the losses are directly affected by land use type and man-made changes that occurring due to development and land surface modifications. The two terms that are used for direct water losses to the atmosphere are “evaporation” and “evapotranspiration”. “Evaporation” applies to areas of open water, where water evaporates directly from the surface of the water body, such as pond, lake, river, canal, drainage way and other ponded areas. “Evapotranspiration” applies to the combined water losses from all land surfaces and plants which are not open water. This includes grasses, crops, weeds, shrubs, trees, bare ground, rooftops, pavement and any other ground cover that allows for trapping and/or extracting water from the ground and then releasing it into the atmosphere. All these evaporative water losses are significant and can account for up to 90 percent of all water sources in some areas.

These components are much harder to obtain and/or estimate and require further explanation. The following is a literature review and analysis of evaporation and evapotranspiration data completed by Dr. Eslinger, which provides a good summary for a range of parameters that occur in the natural and man-made systems of Florida. These may not apply to other areas of the state or to areas outside Florida. However, the data review and analytical approach presented below can be repeated for any area of study and a site-specific table of typical rates can be similarly generated. Therefore, the data presented below can be used directly in a central Florida area and, with some minor adjustments, can be expanded to all of Florida. Other states and countries should carefully review and analyze the data for their specific area and generate similar summary tables to use in their region.

A Survey of Annual Evaporation and Evapotranspiration Rates in Florida and an Analysis of Some Methods for Calculating Those Rates

Prepared by:
David L. Eslinger, Ph.D.

Approach

A review was conducted of the peer-reviewed hydrology literature, of published Federal government documents, and of web-based resources. Methodologies suggested in this report are from published reports in the peer-reviewed literature or in government (state and Federal) handbooks, etc. Web-based results may be presented as informational, but are not considered authoritative for the purposes of this report.

In estimating evaporation (E) and evapotranspiration (ET) from the use/land cover types, three groups with similar data availability/hydrologic considerations emerge: open water/wetland, impervious surfaces, and pervious/vegetated surfaces. For open water and wetland, E and ET annual rates from Florida, or similar southern U.S. climates, were available and are reported. For the impervious surfaces, however, individual estimates of E, as are occasionally reported in the literature, do not seem to be of much value for the purpose of estimating water budgets in Florida. Instead in this report, evaporation rates are reported as a fraction of annual rainfall. The fractional evaporation should be less variable between areas and times than actual evaporation rates are, and allows one to use results of studies done on similar roof types, paving, etc., but not done in Florida.

For pervious surfaces, this report contains a mixture of actual ET rates and crop coefficients. Evapotranspiration rates representative for Florida were found for several different types of pervious land cover. However, crop factors were found for more cover types and more time periods. They may be more useful for the present work. For completeness, a brief explanation of the crop factor’s use is included below.

In addition, the general, descriptive categories of unpaved, irrigated and non-irrigated surfaces are redefined into more specific land use categories of forested (upland and wetland), golf-courses, agricultural, etc. Wet versus dry seasonal differences were also evaluated. Those are reported in the sections under each substrate type, when available.

Methodologies and Rates

Methodology overview

Actual evaporation, E_a, and evapotranspiration, ET_a, are difficult to measure directly. Frequently they are calculated from a reference evapotranspiration rate, ET_o, multiplied by some reduction factor, K_c, the crop coefficient:

$$ET_a = K_c \times ET_o \qquad 1).$$

Defining a reference evapotranspiration is a useful concept because ET_o is not a function of crop age, health, etc. It is only a function of climatic variables (Allen et al., 1998). The crop coefficients, K_c, depend on the individual crops of interest, their age, health, etc.

Although ET_o is not a function of crop dynamics, it is created in reference to a **specific crop surface**. There are two crops most commonly used to derived reference evapotranspiration rates: a 0.15 m tall grass crop — used for a short vegetation rate, ET_o — and a 0.5 m tall alfalfa crop — used for tall vegetation rate, ET_r. However, ET_o, in turn, is difficult to measure directly, so it can be derived from local meteorological data using any one of a number of empirically derived equations, or estimated from field-measured evaporation. Because of the number of different equations to calculate ET_o, the American Society of Civil Engineers reviewed most methods and have recommended one standardized reference equation and two standardized reference surfaces — the short and tall crops defined above (ASCE SRETC, 2000). The standard reference equation is a simplified form of the ASCE-Penman Monteith equation (Jensen et al., 1990). Tables providing needed input parameters are given in ASCE SRETC (2000).

Field measurements of evaporation from a standardized open pan (pan evaporation, E_{pan}) are also a common way to find ET_o, using a pan coefficient, K_{pan} in a method similar to that used to find ET_a:

$$ET_o = K_{pan} \times E_{pan} \qquad 2).$$

Note that the pan coefficient is not the same as a crop coefficient, with which they are sometimes confused in the literature. However, now there is a direct linear relationship between actual evapotranspiration for a particular crop, ET_a, and pan evaporation, E_{pan}:

$$ET_a = K_c \times K_{pan} \times E_{pan} \qquad 3).$$

Frequently E_{pan} cannot be continuously measured. Instead, E_{pan} is itself calculated from environmental inputs (*e.g.*, wind speed, temperature, relative humidity) using one of a variety of different formulations. Irmak and Haman (2003) tested five different methods of estimating E_{pan} values for the Gainesville area of Florida, which they put forward as representative for Florida's humid climate. They used a 23-year long record of field-measured E_{pan} values, and found the Kohler-Nordenson-Fox (KNF) method (Kohler, et al., 1955) to be the best method by far. The other methods tested were the Penman (Penman, 1948), Christiansen (Christiansen, 1968), Priestly-Taylor (Priestly and Taylor, 1972), and Linacre (Linacre, 1977) methods.

Evaporation from impervious surfaces is generally estimated differently, usually by water budget techniques, *i.e.*, the amount of water lost that cannot be attributed to runoff, infiltration, or other identified process, is attributed to evaporation. Runoff from impervious surfaces, such as roofs, roads, sidewalks, parking lots, etc., frequently is estimated using the SCS curve number approach put forward in Technical Reference-55 (USDA NRCS, 1984), using a curve number, CN, of 98. One of the variables in the runoff calculation is the *initial abstraction*, defined as all losses from rainfall before runoff begins: evaporation, infiltration, storage in interstitial spaces, interception by vegetation, etc. Using standard SCS methodology, a CN=98, produces an initial abstraction of 0.04 inches of water. It is important to note that this initial abstraction is the amount lost per rainfall event. If using the SCS method for average annual estimates, one must also know the annual average number of "raining days" in order to estimate annual evaporation. However, even if that information is known, the use of the SCS initial abstraction approach for estimating evaporation from impervious surfaces is not recommended. It was found to seriously underestimate evaporation and infiltration in several studies, which are discussed in the Impervious Surfaces section, below.

Although evaporation and evapotranspiration rates are the primary components for this review, other processes mentioned in the reviewed literature (*i.e.*, vertical conductance, infiltration) are discussed in the following sections when it appears they might be relevant to creating accurate water budgets.

Water and wetlands rates

Open water

Evaporation estimates are reported for several Florida lakes and open water in wetland areas. They were measured using either pan evaporation or heat budget techniques. All rates reported below were measured over at least a one year period. The longest study was done at Lake Okeechobee, where evaporation rates were measure at seven stations for five years (Abtew, 2001). Annual evaporation rates are reported below in Table 1.

Table 1. Open water evaporation rates

Lake	**Region**	**Annual Evaporation**		**Reference**
		(m/yr)	**(in/yr)**	
Barco	North-central	1.51*	59.4*	Sacks et al., 1994
Five-O	Panhandle	1.28*	50.4*	Sacks et al., 1994
Ft. Drum Marsh	East-Central	1.17	46.1	Mao et al., 2002
Lowry (Sand Hill)	North-central	1.11	43.7	Motz et al., 2001
Magnolia	North-central	1.31	51.6	Watson et al., 2001
Okeechobee	South	1.32	52.0	Abtew, 2001

*Reported as "Higher than normal", perhaps due to drought conditions at the time of the study.

From the Lake Okeechobee data in Table 1, which is from the longest, most extensive study of those noted, we can calculate a representative annual ET_o for the south Florida region. I used the methodology reported in SFWMD (1999) so that the ET_o used in this report will be consistent with results from the South Florida Water Management Model, SFWMM, (SFWMD, 1999). Removing the daily correction coefficient and the areal weighting factors from the SFWMM model equation 2.2.1 gives the following relationship between ET_o and Lake Okeechobee annual evaporation, E_{LOK}:

$$E_{LOK} = 0.865 \times 1.1 \times ET_o \qquad \text{4a), or, rearranging}$$
$$ET_o = E_{LOK}/(0.865 \times 1.1) \qquad \text{4b),}$$

where:

E_{LOK} = Annual Lake Okeechobee Evaporation = 52.0 in (Abtew, 2001), 0.865 = K_{pan} (Shih, 1980),
1.1 = a "completely flooded vegetation" factor (more in water table section below), and
ET_o = Reference crop evapotranspiration = 54.65 inches annually

Note that there were significant seasonal variations reported, with open water evaporation rates highly seasonal and dependent on solar radiation and air temperature. Lake morphology was also found to make some differences in seasonality of evaporation in two north Florida lakes (Sacks et al., 1994). The timing of the highest evaporation rates changed depending on the depth of the lakes. This was attributed to the different heat capacities of the lakes. The shallower (3 m average depth) Lake Barco, had a lower heat capacity and therefore was more responsive to early heating events. This behavior leads to it having more evaporation in winter and early spring than the deeper (9.5 m average depth) Lake Five-O. However, later in the year, the relationship reversed. Once the deeper lake was well heated, it had higher evaporation rates in late summer and autumn, as both lakes began cooling.

Another water budget process that may be of interest, and that had rates reported in the literature, is vertical conductance, or the leakage of water through a lake bottom into the Florida Aquifer. Annual vertical conductance rates were reported for two north-central Florida lakes: Lake Lowry and Lake Magnolia. The annual vertical conductance rates were significantly higher than the evaporation losses: 2.88 and 1.48 m/year for vertical conductance versus 1.31 and 1.11 m/year evaporation for Lake Magnolia and Lake Lowry, respectively (Watson et al., 2001, Motz, et al., 2001). The vertical conductance process was reported as a typical feature for karst lakes in Florida (Motz et al., 2001).

Wetlands

Several studies of wetland evapotranspiration in Florida were reviewed and rates are summarized in Table 2. Scientific names for species listed in Table 2 are given in Table 3. Only rates for herbaceous plants and algae are given here; reported ET rates for cypress wetlands are given in the pervious section below, with other forest ET rates. When annual-average daily rates were reported in the literature — the usual case — they are annualized for Table 2 by assuming a 365 day year. In general, wetland evapotranspiration rates are similar to open water evaporation rates on an annual basis. However, on a seasonal basis there is evidence that some plant communities may have higher evapotranspiration rates in the summer. This is not a universally accepted finding. There are also a number of studies that explain the observed increased ET rates as artifacts of the experimental design, particularly of the increased edge or sidewall area of the studied vegetation.

Wetland areas all had strong seasonal patterns of ET, with most plants ET rates peaking in May, closely followed by June and July (Mao, et al, 2002; Abtew, 1996; Rushton, 1996). Minimum rates occurred in December and January. The highest monthly averaged daily rates of ET generally differed from the lowest monthly average rates by a factor of 2.5 to 4. All studies reported in Table 2 were carried out over one or more years, except the one done on Paynes Prairie (Jacobs, et al., 2002), which occurred over a two month period: May and June. The reported rates are therefore probably too high for annual rates by a factor of two or more. Also note that that particular study was done in a time of drought, which may have lowered ET rates due to lower amounts of soil moisture available. The Paynes Prairie study is reported here to give an indication of the extremes for wetland rates.

Table 2. Wetland vegetation evapotranspiration rates

Vegetation	**Region**	**Annual Evapotranspiration**		**Reference**
		(m/yr)	**(in/yr)**	
Cattail	Fort Drum Marsh, Upper St. Johns River Basin	1.19	46.7	Mao et al., 2002
Young sawgrass		1.34	52.6	
Mature sawgrass		1.29	50.9	
Cattail	Everglades Nutrient Removal Project[3]	1.31	51.7	Abtwe, 1996
Mixed Marsh[1]		1.28	50.3	
Water/Algae[2]		1.35	53.2	
Mixed shallow pond[4]	Tampa	1.28	50.2	Rushton, 1996
Prairie,drought[5]	Paynes Prairie	1.52[6]	59.8[6]	Jacobs et al., 2002
[1]Spikerush, pickerel weed, arrowhead, duckpotato, maidencane and sawgrass				
[2]Open water with periphyton/submerged macrophyte community				
[3]Located 40 km west of West Palm Beach (26° 28' N, 80°25' W)				

[4] Pickerel weed, arrowhead, water lilies and grass
[5] Maidencane, mock bishop's weed and dog fennel. Drought conditions occurred prior to and during the study.
[6] Not measured annual rates. Annualized monthly averaged rates over May and June.

Table 3. Common and scientific names of plant species listed

Common name	Scientific name	Common name	Scientific name
Arrowhead	*Sagittteria latifolia*	Ray grass	*Lolium perene*
Cattail	*Typha domingensis*	Sawgrass	*Caladium jamaicense*
Cypress	*Taxodium ascendens*	Spikerush	*Eleocharis spp.*
Dog fennel	*Eupatorium capillifolium*	Pickerel weed	*Pontederia cordata*
Duckpotato	*Sagittteria lancifolia*	Pine, slash	*Pinus eliotti*
Dwarf horseweed	*Conyza canadensis*	Maidencane	*Panicium hemitomon*
Fescue, creeping red	*Festuca rubra*	Mock bishop's weed	*Ptilimniom capillaceum*
Kentucky blue grass	*Poa pratensis*	Natalgrass	*Rhynchelytrm repens*
Ragweed	*Ambrosia* sp		

Impervious Area rates

Although for impervious surfaces it seems reasonable to use the initial abstraction as an estimate of evaporation (*i.e.*, water that does not run off of an impervious surface will eventually be lost as evaporation), several recent studies indicate that there can be substantial evaporation from and **infiltration** into "impervious" surfaces. Synopses of these studies are given below.

Paved surfaces

Ragab, *et al.*, (2003b) acknowledged that the current consensus among urban hydrologists is that water losses from impervious surfaces are small. However, in a yearlong study of 5 sites, in England: 3 parking lots (2 asphalt and 1 concrete), 1 small road and a grass plot for control; they found the impervious surface runoff:rainfall ratios were 0.7, 0.9 and 0.5 for annual, winter and summer, respectively. Measured infiltration fraction depended on road age and condition; increasing with age and number of cracks, patches, etc. Also, concrete pavers were more porous/permeable than asphalt. Annual rainfall was ~24 inches. Annual evaporation averaged 21% to 24% of annual rainfall with higher rates in the summer than in the winter.

In a series of shorter duration experiments using asphalt plates, Ramier et al. (2004) found similar results. Evaporative losses from the asphalt were generally approximately 25% of the rainfall. Infiltration ranged from only 5% for traditional asphalt to 58% for porous asphalt.

Note that in areas where paving is done with "pervious" pavers, there can also be large differences in the rate of infiltration of water through the pavers, depending on the age and wear of the pavers. Gregory (2004) found large differences in infiltration rates (in a study in the Gainesville, FL) area between areas covered with the same pervious pavers. The differences were attributable to differences in wear, with the lowest infiltration rates occurring in the areas which had been subjected to the most use.

Given these studies, the traditional SCS approach (i.e., using the standard curve number and initial abstraction) of estimating impervious runoff and taking all "non-runoff" as evaporation will significantly overestimate the runoff volume and underestimate both evaporative losses and ground water impacts.

Rooftops

Similar to paved areas, rooftop evaporation was found to be considerable and the use of a SCS curve number approach is not a good assumption. Ragab, et al., (2003a) studied several different roof shapes and orientations. All had the same type of roof material (unspecified) and all were built in the 1960's. Ragab et al. found that runoff and evaporation from these roofs was a strong function of roof slope and orientation to the prevailing wind direction. The steepest slope (50°) had the highest amount of runoff, but the maximum observed runoff throughout the one year study was still only ~91% of rainfall; therefore, 9% of rainfall was lost to evaporation. On an annual basis, evaporation from the 50° roof averaged 14.7% of annual rainfall. For the 22°sloped roof house with the same aspect, annual evaporation averaged 24.7% of annual rainfall. For two flat roofed houses, evaporation averaged 30% to 39% of annual rainfall.

Evaporation on roofs with 22° slopes ranged from 13% to 25% of annual rainfall. The differences were due to orientation of the houses. The highest evaporation rate was found for the roof that faced both the prevailing wind and the south (note that this should also get more solar heating over the year, a factor not discussed in the Ragab paper). The lowest evaporation rate – which was still 13.5% of the annual average – was for a north sloping roof, which was more sheltered from the wind.

In addition to annual averages, Ragab (2003a) examined some seasonal aspects of runoff. For their location in England, they found higher runoff:rainfall ratios (and therefore, less evaporation as a fraction of rainfall) in winter, when the rainfall rates were maximal. A similar pattern of higher fraction of runoff occurring in heavy precipitation events is also probably relevant for seasonal differences in Florida. However, given the much higher temperatures in Florida than in England, and the potential differences in the timing of the maximum rainfall events, the actual ranges found in the Ragab study should be considered as general guidelines.

Modified SCS approach

The above literature documents that using an SCS approach will only provide a lower limit as to what evaporative losses may be. Because the SCS methodology is derived for individual rain *events*, when it is used with monthly or annual precipitation, one must include the number of rain events into the runoff equation. Then the usual equation

$$Q = (P - I_a)^2 / ((P - I_a) + S) \qquad \text{5a), becomes}$$

$$Q = (P - (n_d \times I_a))^2 / ((P - (n_d \times I_a)) + S) \qquad \text{5b),}$$

where:

Q = Actual runoff,
P = Precipitation, in inches,
I_a = the initial abstraction, in inches,
S = the saturation value, in inches, and
n_d = the number of rain events in the time period over which P was measured.

Note that a raining event is a period of rain followed by a period of complete evaporation from the impervious surfaces. Given the heat in Florida, there could be more than one of these events in a given day.

The thirty-year (1971-2000) averages of monthly and annual precipitation for the Central Florida region (NCDC climate division 803) were obtained from the National Climatic Data Center (NCDC, 2002). Applying the methodology in Equation 5b to the monthly data using different numbers of raining days gives annual evaporation estimates as shown in Table 4.

Table 4. Annual evaporation estimates from impervious surfaces using modified SCS methodology.

Number of rainfall events / month	1	5	10	15	20
Annual Evaporation (in/yr)	2.8	4.8	7.2	9.6	12.1
Annual Evaporation as percent of annual rainfall[1]	5%	9%	14%	19%	23%
[1] 1971-2000 annual average rainfall is 51.6 inches					

Pervious Areas

ET rates from a general class of "unpaved" areas, with "irrigated", "non-irrigated" and "golf courses" are typically of interest and therefore representative ET rates for land use classes likely to be found in central Florida, both in urban/suburban areas and undeveloped and agricultural areas are presented herein.

Golf courses and recreational grasses

Representative measured annual evapotranspiration rates from golf course in Florida were difficult to obtain from the primary literature because the daily water management plan for a particular course is highly manipulated. It is one of the methods most used to regulate the quality of the turf. If there are insect problems, dry weather, heavy use, etc. watering may be increase, leading to increased evapotranspiration rates. Devitt et al. (1992) showed a strong seasonality in K_c for two golf courses and park turf plot. Their results were from actual working sites and represented the difference seen in actual managed grasses. Their golf K_c values ranged from 0.44 to 0. 89, and their park K_c values ranged between 0.33 and 0.60, over the same two year period.

Given that K_c for grasses varies quite a lot and is heavily controlled, crop coefficients are available for grasses typically used on golf courses, but the crop coefficients vary throughout the year. Using any one of them on an annual basis is not a good assumption. However, applying those crop coefficients to the reference evapotranspiration derived from Equation 4) gives a reasonable estimate of the range of annual ET losses. Values for a few reported ranges of golf course crop coefficients under a variety of management conditions and for other recreational grasses are given in Table 5, below.

Table 5. A range of turf evapotranspiration rates calculated from ET0 from Eq. 4.

Turf type	K_c	Annualized Evapotranspiration[1] (m/yr)	Annualized Evapotranspiration[1] (in/yr)	Reference
Golf course, warm season	0.75	1.04	40.99	New Mexico State Univ. web site[2]
Golf course, cool season	0.85	1.18	46.45	
Park grass, warm season	0.65	0.90	35.52	
Fairway mix[3,4]	0.60	0.83	32.79	Costa et al., 2000
Fairway mix[3,5]	1.70	2.36	92.91	
Fairway mix[3,6]	0.80	1.11	43.72	
Fairway mix[3,7]	1.10	1.53	60.12	

[1] Caclualated using Eq. 1) and ET_o=54.65 in/yr from Eq. 4).

[2] http://weather.nmsu.edu/nmcrops/ornamentals/truf.htm

[3] Creeping red fescue - 60%, Ray grass - 20% and Kentucky blue grass - 20%

[4] Watered with potable water with added nitrogen fertilizer (30kg ha^{-1} $month^{-1}$)

[5] Watered with potable water, no nitrogen fertilizer

[6] Watered with reclaimed water with without fertilizer, lowest K_c cultivar

[7] Watered with reclaimed water with without fertilizer, highest K_c cultivar

Forested, agricultural and miscellaneous vegetation

Evapotranspiration rates for several type of forested cover are given in Table 6. Forest management practices can have a large impact on ET_a from a given plot of land and can even impact the water table (Sun et al., 2000). However, the values in Table 6 should be representative. Also in Table 6 is an ET estimate for successional weeds that moved in after land clearing. In Table 7, annual ET values are calculated for a variety of land cover/land use types using average K_c values and ET_o calculated in Equation 4. These are the LC/LU types used in the South Florida Water Management Model (SFWMD, 1999) and should be representative for southwestern Florida as well. The monthly K_c values used to calculate the annual averages in Table 7 are given in Table 8.

Table 6. Forest and weed evapotranspiration rates

Forest type	**Region**	**Annual Evapotranspiration**		**Reference**
		(m/yr)	**(in/yr)**	
Slash pine	Near Gainesville, FL	0.80	31.3	Liu, et al., 1998
Cypress wetland		0.97	38.3	
Pine Forest	Bradford, FL	1.02	40.0	Lu, et al., 2003
Pine	Gainesville, FL	1.03	40.5	Lu, et al., 2003
Okefenokee Swamp Upland	South Georgia	0.88	34.6	Rykel, 1984[1]
Pocosin	NC	0.67	26.4	Richardson, 19831
Cypress Pond/Pine Flat	FL	1.27	50.0	Heimburg, 1976[1]
Pine Flat	FL	0.77 to 1.18	30.3 to 46.5	Heimburg, 1984[1]
Cypress Pond/Pine Flat	FL	1.31	51.6	Riekerk, 1989[1]
Cypress Pond/Pine Flat	FL	1.15	45.3	Riekerk, et al., 1995[1]
Wet pine flat	NC	1.06	41.6	McCarthy et al., 1991[1]
Wet pine flat	NC	0.94	37.1	Amatya et al., 1996[1]
Successional weeds[1]	Orange Co., FL	0.68	26.8	Sumner, 1996
[1]as cited in Miwa, 1999				
[2]Natalgrass, dog fennel, dwarf horseweed, and ragweed				

Table 7. Annual evapotranspiration for land cover types in the South Florida Water Management Model (v3.5) (SFWMD, 1999).

	Land Use	Type/Description	K_c	ET_a
1	Urban	Low density	0.595	32.50
2	Agriculture	Citrus	0.702	38.34
3	Wetland	Marsh	0.811	44.34
4	Wetland	Sawgrass plains	0.844	46.10

5	Wetland	Wet prairie	0.730	39.88
6	Rangeland	Shrubland (scrub and shrub)	0.861	47.04
7	Agriculture	Row (or truck) crops	0.511	27.92
8	Agriculture	Sugar cane	0.590	32.23
9	Agriculture	Irrigated pasture	0.568	31.05
10	Wetland	Stormwater treatment area and above-ground reservoir	0.872	47.66
11	Urban	High density	0.385	21.02
12	Forest	Forested wetlands	0.754	41.19
13	Forest	Mangroves	0.839	45.83
14	Forest	*Melaleuca*	0.875	47.82
15	Wetland	Cattail	0.824	45.01
16	Forest	Forested	0.775	42.37
17	Wetland	Modified ridge & slough	0.716	39.11
18	Wetland	Marl prairie 3.0	0.925	50.57
19	Wetland	Mixed cattail / sawgrass	0.832	45.47
20	Water	Open water (deep excavated reservoirs)	1.000	60.12
21	Wetland	Modified ridge & sawgrass-invaded slough	0.798	43.61

Table 8.
Crop coefficients, K_c, from South Florida Water Management Model (v3.5) (SFWMD, 1999)

Use	Type/Description	Jan.	Feb.	Mar.	Apr.	May	Jun.
Urban	Low density	0.556	0.502	0.534	0.542	0.562	0.562
Agri.	Citrus	0.701	0.693	0.610	0.542	0.661	0.710
Wetland	Marsh	0.805	0.772	0.810	0.816	0.825	0.825
Wetland	Sawgrass plains	0.815	0.790	0.830	0.840	0.852	0.868
Wetland	Wet prairie	0.715	0.700	0.720	0.735	0.740	0.740
Range	Shrubland (scrub/shrub)	0.855	0.802	0.850	0.875	0.875	0.871
Agri.	Row (or truck) crops	0.374	0.380	0.670	0.613	0.697	0.634
Agri.	Sugar cane	0.468	0.330	0.423	0.516	0.770	0.960
Agri.	Irrigated pasture	0.380	0.385	0.578	0.613	0.770	0.941
Wetland	Stormwater treatment area /above-ground reservoir	0.852	0.802	0.850	0.875	0.883	0.881
Urban	High density	0.363	0.321	0.352	0.361	0.372	0.372
Forest	Forested wetlands	0.723	0.702	0.745	0.750	0.770	0.760
Forest	Mangroves	0.791	0.760	0.830	0.855	0.882	0.880
Forest	*Melaleuca*	0.800	0.770	0.850	0.880	0.910	0.900
Wetland	Cattail	0.795	0.770	0.800	0.810	0.822	0.838
Forest	Forested	0.743	0.722	0.768	0.773	0.783	0.784
Wetland	Modified ridge & slough	0.705	0.692	0.710	0.715	0.715	0.710

Wetland	Marl prairie 3.0	0.893	0.862	0.905	0.933	0.933	0.921
Wetland	Mixed cattail / sawgrass	0.800	0.790	0.810	0.820	0.832	0.848
Water	Open water (deep excavated reservoirs)	1.000	1.000	1.000	1.000	1.000	1.000
Wetland	Modified ridge & sawgrass-invaded slough	0.775	0.750	0.800	0.810	0.820	0.810
Wetland	Cypress prairie (hydrologically similar to wet prairie)	0.742	0.725	0.760	0.761	0.765	0.775

Table 8 (continues)

Crop coefficients, K_c, from South Florida Water Management Model (v3.5) (SFWMD, 1999)

Use	Type/Description	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Urban	Low density	0.628	0.706	0.702	0.686	0.604	0.552	0.595
Agri.	Citrus	0.744	0.810	0.822	0.702	0.723	0.700	0.702
Wetland	Marsh	0.831	0.845	0.841	0.802	0.784	0.781	0.811
Wetland	Sawgrass plains	0.882	0.910	0.910	0.840	0.795	0.790	0.844
Wetland	Wet prairie	0.740	0.750	0.750	0.735	0.730	0.701	0.730
Range	Shrubland (scrub/shrub)	0.881	0.901	0.901	0.882	0.824	0.811	0.861
Agri.	Row (or truck) crops	0.412	0.413	0.458	0.431	0.507	0.541	0.511
Agri.	Sugar cane	0.709	0.656	0.677	0.495	0.518	0.554	0.590
Agri.	Irrigated pasture	0.662	0.613	0.606	0.396	0.474	0.400	0.568
Wetland	Stormwater treatment area /above-ground reservoir	0.901	0.941	0.952	0.892	0.824	0.811	0.872
Urban	High density	0.394	0.443	0.421	0.453	0.402	0.361	0.385
Forest	Forested wetlands	0.770	0.790	0.790	0.740	0.770	0.735	0.754
Forest	Mangroves	0.882	0.904	0.900	0.824	0.803	0.753	0.839
Forest	*Melaleuca*	0.910	0.970	0.970	0.860	0.880	0.800	0.875
Wetland	Cattail	0.852	0.894	0.890	0.830	0.795	0.787	0.824
Forest	Forested	0.805	0.820	0.820	0.760	0.771	0.754	0.775
Wetland	Modified ridge & slough	0.721	0.740	0.740	0.715	0.724	0.701	0.716
Wetland	Marl prairie 3.0	0.957	0.975	0.970	0.920	0.941	0.894	0.925
Wetland	Mixed cattail / sawgrass	0.862	0.904	0.900	0.835	0.795	0.788	0.832
Water	Open water (deep excavated reservoirs)	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wetland	Modified ridge & sawgrass-invaded slough	0.820	0.825	0.825	0.780	0.790	0.771	0.798
Wetland	Cypress prairie (hydrologically similar to wet prairie)	0.791	0.815	0.815	0.772	0.764	0.741	0.769

Water table effects and wet versus dry seasonal factors

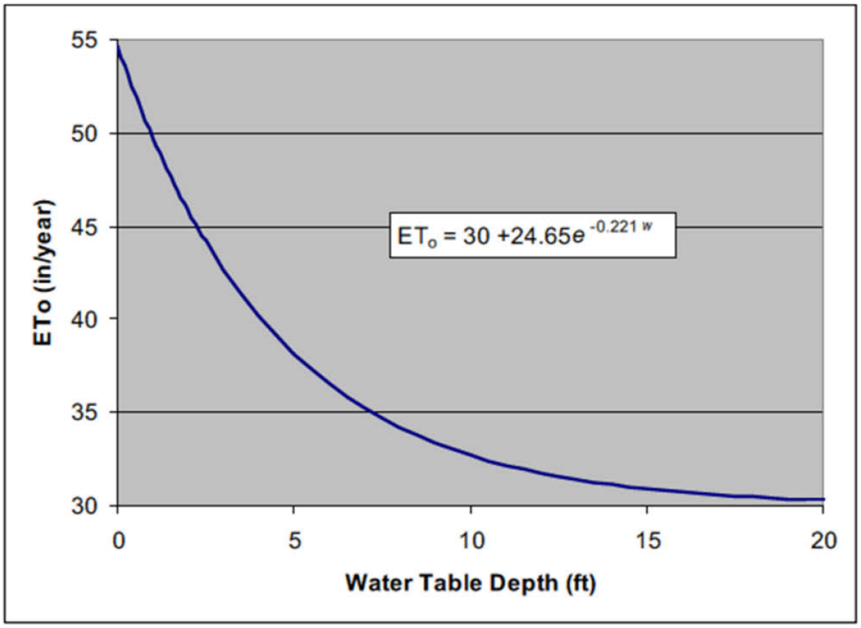
Most seasonal differences have been covered above in each particular section. In general, E_a and ET_a exhibit strong seasonality. Open water evaporation rates were highly seasonal and depended strongly on solar radiation and air temperature. As general rule, evapotranspiration crop coefficients also are strongly seasonal, with 10%-50% increases during dry seasons (Allen, 1998). K_c increases for shorter, denser crops (e.g., beans, grass) are closer to 10%, whereas K_c for taller crops (e.g., sugar cane) ranged closer to 50%. Table 7 shows monthly K_c values for standard substrates used in the South Florida Water Management Model (SFWMM, SFWMD, 1999). The differences observed in those K_c values also range from ~10% to 50%.

Water table depth also influences E and ET, and, in turn, may be influenced by management practices. The maximum evapotranspiration has been expressed by an exponentially decreasing function of distance to ground water table (Tibbals, 1978). For this study, the relationship between maximum ET_o and water table depth is shown in Figure 1 and defined by Equation 6:

$$ET_o = 30 +24.65-0.221\ w \qquad 6),$$

Where *w* is distance to ground water in feet (after Tibbals, 1978).

Figure 1. Maximum ET0 as a function of water table depth.



Note that only one parameter in Equation 6 is changed from Tibbals (1978) original equation. That change was needed to fit his recommended curve shape and asymptote (*i.e.*, same asymptote, same exponent) to the maximum ET_o value of 54.65 in/year in Equation 4. in the SFWMM model, distance to water table is also considered important. It is used as a modifier to the K_c values given in Tables 7 and 8. Figure 2 shows a conceptual cartoon illustrating the changes applied in SFWMM to K_c depending on water table depth relative to certain model parameters.

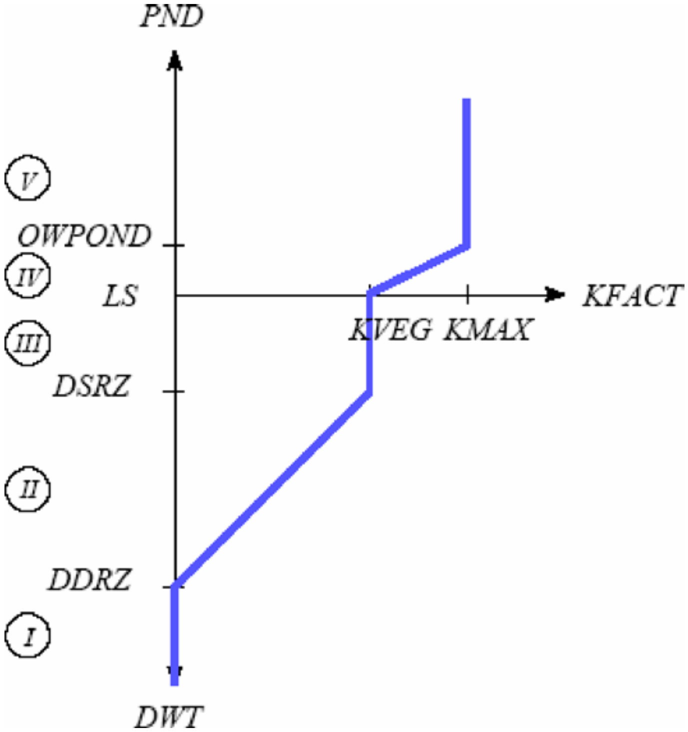


Figure 2. Variation of K_c (here shown as KFACT) as a function of water table depth. When there is a deep water table (DWT) then K_c is some minimum value. K_c increases between a threshold value and a representative root depth, above which it is assumed to be it's standard value given in Table 7, here shown as KVEG. As the water table rises above the ground and the plants become submerged, KFACT increases to the KFACT of open water. (from SFWMD, 1999)

In addition to K_c, and hence, ET_a, varying with water table depth, note that Sun et al. (2000) showed how there was a ground-water table rise after forest harvesting.

Summary and Central Florida Recommendations

Based upon the ranges of reported evaporation and evapotranspiration rates and processes for various surfaces described above, I have reviewed the presented data for the various surfaces of interest and have estimated representative average rates for the annual water budget for Central Florida areas (Lake County, Marion County, Sumter County, and Orange County). hese rates are given in Table 9, below.

Table 9. Representative Evaporation/Evapotranspiration rates for Central Florida, and assumptions used to derive them.

Surface Type	Annual E/ET (in/year)
Open Water	52
Wetlands (Average of non-drought studies in Table 2)	51
Rooftops	10
Paved Surfaces	12
Golf Course (irrigated surfaces)	60
Residential/Commercial Landscaped Lawns (irrigated surfaces)	58- 60
Non-irrigated surfaces (rangeland/shrub), high water table (1-3 ft)	37- 43
Non-irrigated surfaces(rangeland/shrub), low water table (~10 ft)	33

Specific factors used in determining values in Table 9.

Values in Table 9 were taken directly from the representative literature for Florida, when available. When values were not directly found in the primary literature, they are based on the ET_o value derived from 5-20+ year averages of open water evaporation from central and south Florida lakes (Okeechobee and Magnolia). The rooftop rate is representative of an average of 10-15 raining events per month. The values are consistent with evaporation from moderately sloped roofs. The pavement value is based on the same assumed rainfall events, but assumes a small loss (20% of the evaporative loss) due to infiltration into cracked pavement, some concrete sidewalks and pavement, etc. Again, rates are consistent with those reported in the literature (*e.g.*, Ragab, 2003b). The irrigated golf course value is consistent with well maintained golf courses watered with reclaimed water, without aggressive fertilization. The irrigated landscape/lawn value, although similar, reflects a more suburban set of assumptions: watering with potable water, less intensively managed and in generally poorer health. The two non-irrigated surfaces are representative of scrub/shrub rangeland, with ET_o calculated from equation 6. The higher evapotranspiration rate is for the shallower water table depth.

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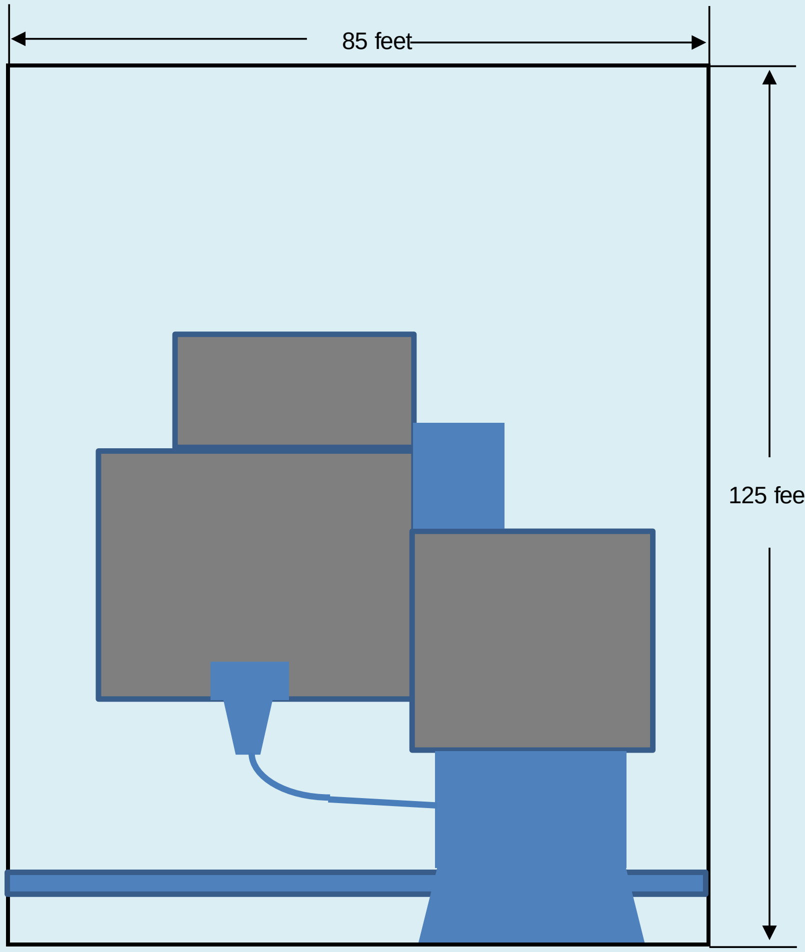
The simplest way to present this approach is to introduce a series of examples. Some examples will be for a typical residential home with a balanced irrigation water demand design and others will be for complete subdivisions with multiple homes and roadways.

Example 1

The following typical house lot and structural layout will be used to set up the water balance calculations for Condition 1 type drainage setting (closed drainage basin):



Typical 1/4 Acre Lot Layout

Total Lot Area	10,625 ft2
▬	2,200 ft2 under roof (house, garage, other)
▬	1,750 ft2 paved (driveway, sidewalk, other)

For this lot layout, we will select the following pre-existing conditions for the lot prior to building the house:

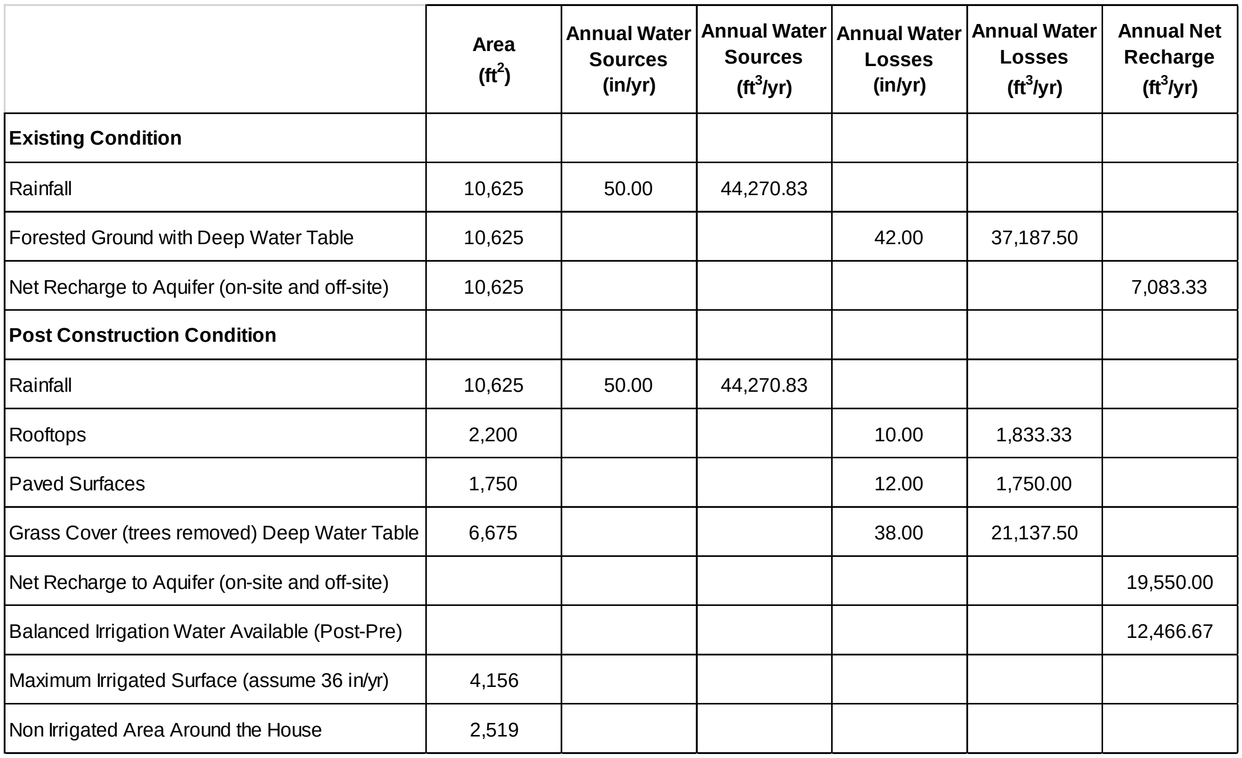
1. The land is located in a closed drainage basin area, Condition 1 setting.
2. All runoff infiltrates back into the soil on-site or at a retention pond nearby.
3. The soil on the lot is clean fine sand.

4. Groundwater below the lot is 6 feet or more below ground surface.
5. The natural soil cover is trees and some shrub vegetation.
6. The property is located in the central Florida area.

To estimate the “balanced irrigation water demand” for the proposed house as laid out in the figure above, it is necessary to estimate the sources and losses of water under existing and post construction conditions. This will be done on an average annual basis. The sources of water for this lot will be the annual rainfall for the area. For central Florida area the annual average rainfall is about 50 inches. The losses of water will be the evaporation and evapotranspiration from existing and post construction surfaces. Utilizing Dr. Eslinger’s study presented herein, the following relevant annual ET data was estimated:

Surface Type	**Annual ET (in/yr)**
Rooftops	10
Paved Surfaces	12
Forested Ground with Deep Water Table (37-47 in/yr)	42
Grass Cover (trees removed) Deep Water Table (33-43 in/yr)	38

To estimate the “balanced irrigation water demand” the following spreadsheet based method can be used, although any simple calculations can be employed for this analysis:



	Area (ft^2)	Annual Water Sources (in/yr)	Annual Water Sources (ft^3/yr)	Annual Water Losses (in/yr)	Annual Water Losses (ft^3/yr)	Annual Net Recharge (ft^3/yr)
Existing Condition						
Rainfall	10,625	50.00	44,270.83			
Forested Ground with Deep Water Table	10,625			42.00	37,187.50	
Net Recharge to Aquifer (on-site and off-site)	10,625					7,083.33
Post Construction Condition						
Rainfall	10,625	50.00	44,270.83			
Rooftops	2,200			10.00	1,833.33	
Paved Surfaces	1,750			12.00	1,750.00	
Grass Cover (trees removed) Deep Water Table	6,675			38.00	21,137.50	
Net Recharge to Aquifer (on-site and off-site)						19,550.00
Balanced Irrigation Water Available (Post-Pre)						12,466.67
Maximum Irrigated Surface (assume 36 in/yr)	4,156					
Non Irrigated Area Around the House	2,519					

Download the above spreadsheet at:
http://www.suncam.com/authors/026Andreyev/209/E1.zip

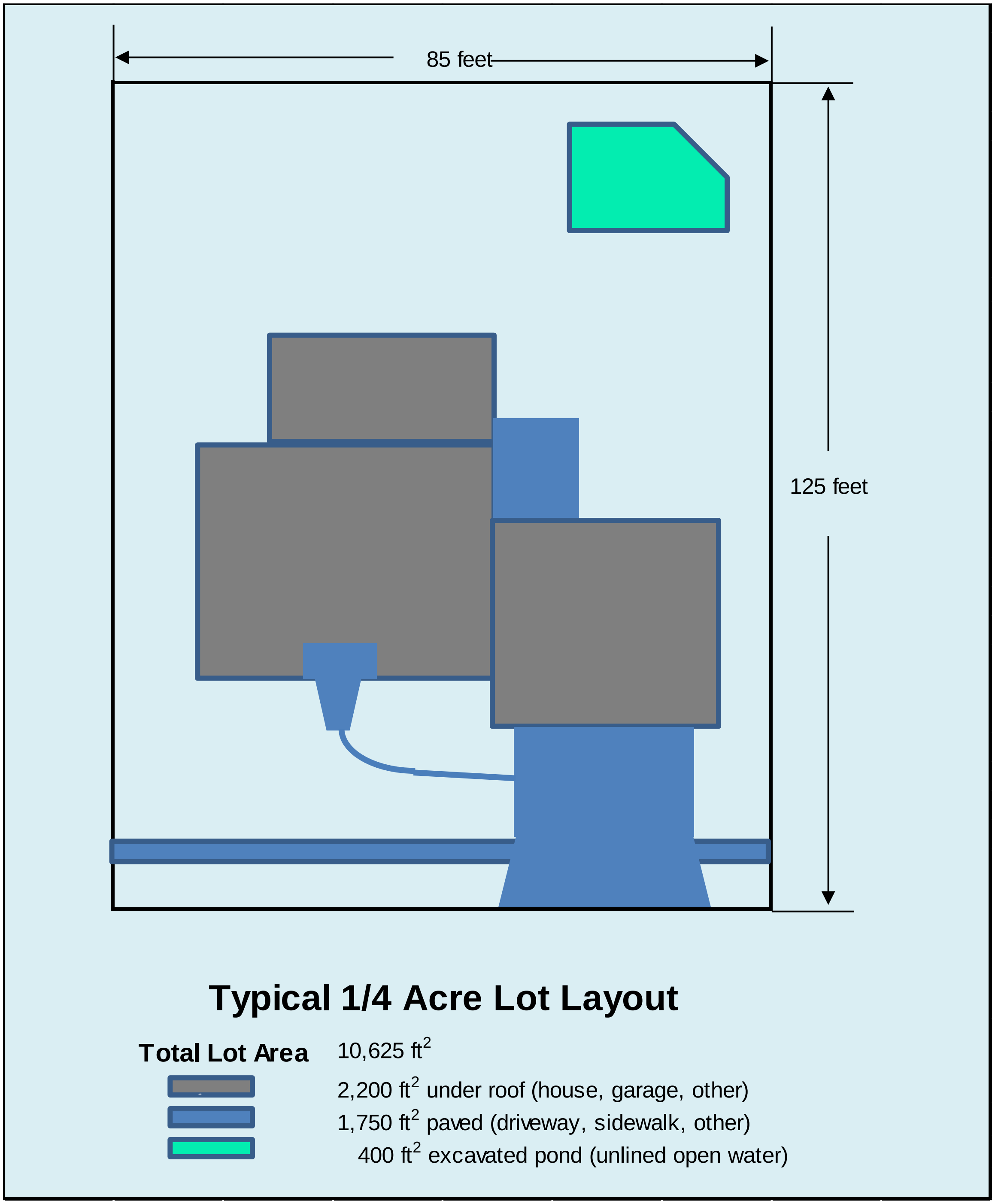
In the table above the balanced irrigation water available was calculated by subtracting the net recharge under existing condition from the net recharge under the post construction condition. This assumes that only the excess aquifer recharge water will be available for irrigation. Any additional irrigation water would create an imbalance of net recharge and could affect the regional groundwater resources, regardless whether the irrigation water comes from an on-site well, public water supply, potable water supply, reclaimed water or any other sources of water.

The maximum irrigated surface was calculated by converting the annual irrigation rate (typically ranges from 30 to 42 inches per year, assumed at 36 in/year for this example) from inches to feet (36"/12 = 3 feet) and then dividing the balanced irrigation water available by the irrigation rate (12,466.67 ft^3/3ft = 4,156 ft^2). This indicates that although the remaining green areas around the house is about 6,675 ft^2, a maximum of only 4,156 ft^2 should be irrigated landscape and the remaining 2,519 f ft^2 should be left un-irrigated. The un-irrigated area can be left as natural buffer with native grasses or shrubs but should not have any irrigation.

The calculated post construction volume of additional water sources have resulted from the improvements made on-site, primarily the impervious surfaces that reduced evapotranspiration losses of water. This method of balanced irrigation water demand can be used to balance the need for irrigation and the preservation of water resources in a region.

Example 2

For this example the same house layout from example 1 will be used but this time the lot will be located in a Condition 2 type drainage setting (some discharge from the drainage basin does occur during heavy storm events). In addition, a small pond will be excavated in the back of the house for decorative/landscaping purposes. The following is a schematic of the lot layout for example 2.



Typical 1/4 Acre Lot Layout

Total Lot Area 10,625 ft^2

▬ 2,200 ft^2 under roof (house, garage, other)
▬ 1,750 ft^2 paved (driveway, sidewalk, other)
🟩 400 ft^2 excavated pond (unlined open water)

For this lot layout, we will select the following pre-existing conditions for the lot prior to building the house:

1. The land is located in a drainage basin area that has shallow water table and various ditches, drainage ways.
2. Some of the runoff discharges to a river and is lost from the drainage basin, Condition 2.
3. Drainage basin studies indicate that annually about 11% of the rainfall is lost to surface water discharge that flows into the ocean.
4. The soil on the lot is mostly fine sand and silty fine sand.
5. Groundwater below the lot is at an average of 2.5 feet below ground surface
6. The existing soil cover is mostly pasture without irrigation.
7. The property is located in south Florida region.
8. Average annual rainfall for this area is estimated at 52.6 inches.

To estimate the “balanced irrigation water demand” for the proposed house as laid out in the figure above, it is necessary to estimate the sources and losses of water under existing and post construction conditions. The evaporation and evapotranspiration for existing and post construction surfaces were estimated from Dr. Eslinger’s study as follows:

Surface Type	**Annual ET (in/yr)**
Rooftops	12
Paved Surfaces	14
Open Water	52
Pasture Grass Cover, Shallow Water Table	43
Grass Cover & Landscaped Areas, Shallow Water Table	43

Using these values the following “balanced irrigation water demand” calculations can be made:

	Area (ft^2)	Annual Water Sources (in/yr)	Annual Water Sources (ft^3/yr)	Annual Water Losses (in/yr)	Annual Water Losses (ft^3/yr)	Annual Net Recharge (ft^3/yr)
Existing Condition						
Rainfall	10,625	52.60	46,572.92			
Pasture grass cover, shallow water table	10,625			43.00	38,072.92	
Discharge from Drainage Basin (at 11%)	10,625			5.79	5,123.02	
Net Recharge to Aquifer (on-site and off-site)	10,625					3,376.98
Post Construction Condition						
Rainfall	10,625	52.60	46,572.92			
Discharge from Drainage Basin (assume = pre)	10,625			5.79	5,123.02	
Rooftops	2,200			12.00	2,200.00	
Paved Surfaces	1,750			14.00	2,041.67	
Pond (open water)	400			52.00	1,733.33	
Grass Cover/Landscape, Shallow Water Table	6,275			43.00	22,485.42	
Net Recharge to Aquifer (on-site and off-site)						12,989.48
Balanced Irrigation Water Available (Post-Pre)						9,612.50
Maximum Irrigated Surface (assume 34 in/yr)	3,393					
Non Irrigated Area Around the House	2,882					

Download the above spreadsheet at:
http://www.suncam.com/authors/026Andreyev/209/E2.zip

In the table above the balanced irrigation water available for the same house layout was reduced from 12,467 ft^3 to 9,613 ft^3 and the maximum irrigated surface was reduced from 4,156 ft^2 to 3,393 ft^2. The reduction is due to the difference in surface cover under existing conditions, the discharge effects and the introduction of an excavated pond. The pond with open water surface increases the evaporation losses and decreases the available irrigation water for the lot. The maximum irrigated surface was calculated by converting the annual irrigation rate estimate from inches to feet (34”/12 = 2.833 feet) and then dividing the balanced irrigation water available by the irrigation rate (9,612.5 ft^3/2.833 ft = 3,393 ft^2). This indicates that although the remaining green areas around the house is about 6,275 ft^2, a maximum of only 3,393 ft^2 should be irrigated (landscape and grass areas) and the remaining 2,882 f ft^2 should be left un-irrigated. The un-irrigated area can be left as natural buffer with native grasses or shrubs but should not have any irrigation.

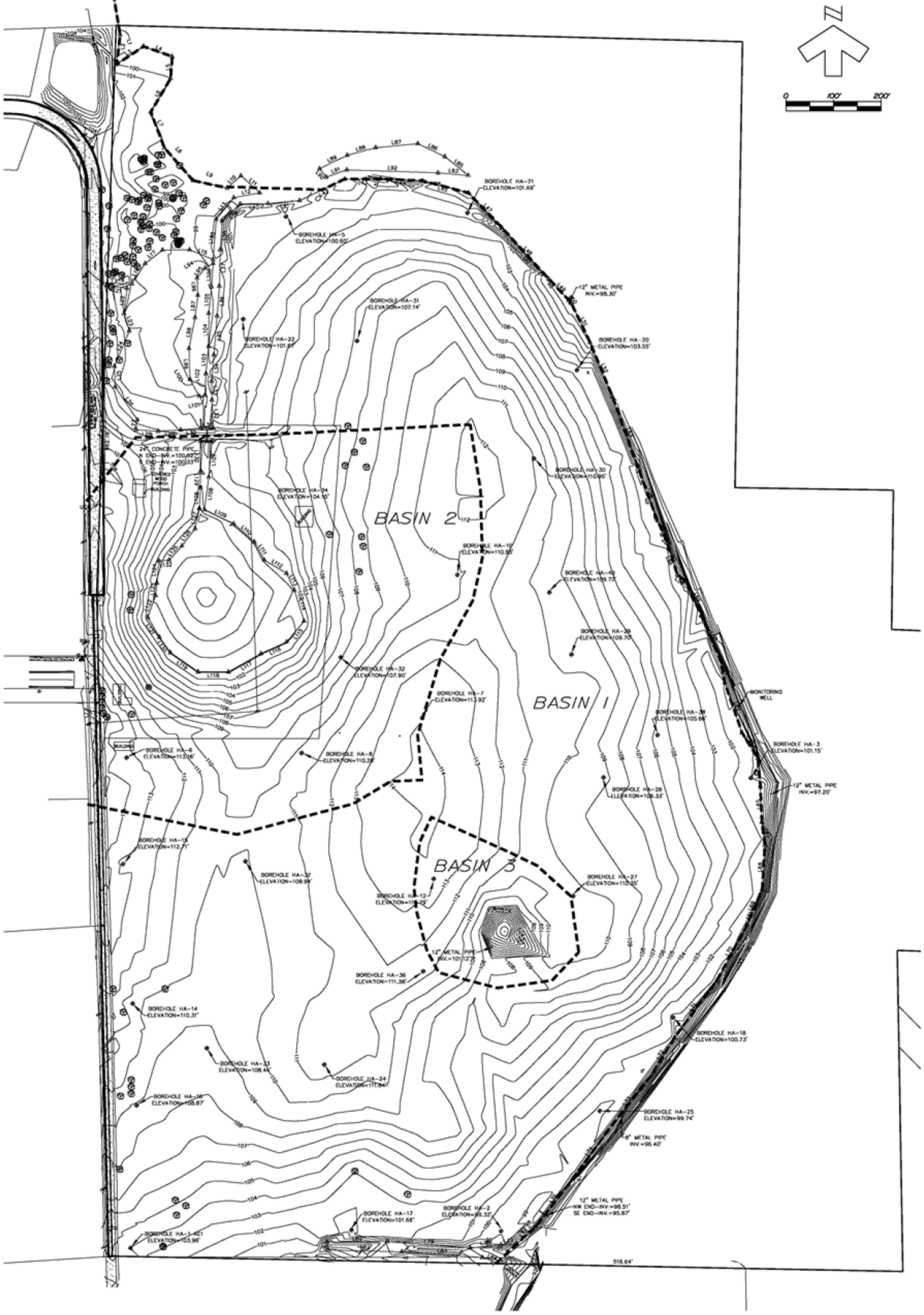
For a location with drainage Condition 3, where the irrigation water supply is extracted from the surficial aquifer, the analysis would be the same as for Example 2. However, if the irrigation water source is extracted from the artesian aquifer then the analysis would not be appropriate since there is no way to recharge the aquifer from on-site sources (recharge from rainfall excess). Then again if water conservation is the primary goal regardless where the irrigation water sources comes from, the balanced irrigation water demand calculations can be applied for any site following the approach of Example 1 or 2.

Example 3

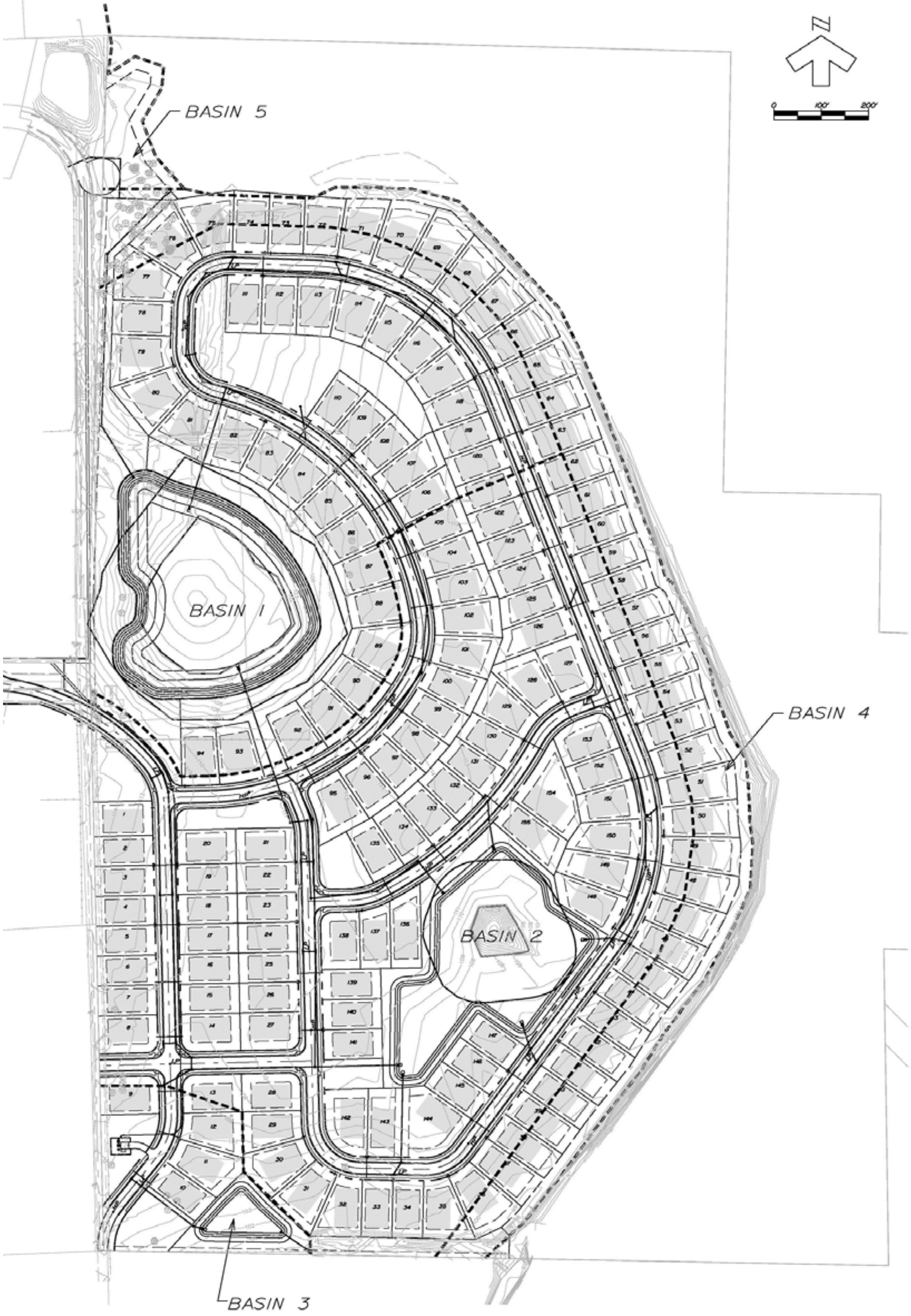
For this example a small residential subdivision will be used, which includes houses, roads, retention ponds and wetlands, to calculate the overall balanced irrigation water demand for the subdivision. This is an actual subdivision that was investigated and permitted. It is located in the Orlando area (central Florida). The drainage basin for this development was internally drained with some off-site runoff but all runoff stays within the drainage basin and all water is recharged back into the surficial aquifer. The surficial aquifer is hydraulically connected to the underlying Floridan aquifer through slow rate vertical leakage.

The following is a layout of the subdivision, where the name and location has been removed from the plans (we will refer to it as ABC Subdivision for the purpose of this example):

Pre-Development Site Plan and Drainage Map



Post-Development Layout and Drainage Map



For this subdivision layout, the following pre-existing conditions were obtained from the project engineer and the geotechnical engineer:

1. The land for ABC Subdivision is located in a closed drainage basin area.
2. Some off-site runoff does occur during heavy rainfall events, but it is retained within the drainage basin in lakes and dry depressions. All rainfall and runoff water is retained within the drainage basin.
3. The soils consist of mostly fine sand and silty fine sand. Some clayey fine sand does exist at depths of 8 to 15 feet but are not continuous and are absent altogether in many areas.
4. Groundwater was found to vary from above ground in the pond and wetland areas to 7 feet below ground surface in the higher topographic areas. The average depth to groundwater is 4.5 feet in the areas outside the forested wetland.
5. The existing soil cover is mostly pasture in the upland areas and forested wetland type cover in the lower topographic areas.
6. Average annual rainfall for this area is estimated at 49.5 inches.

To estimate the “balanced irrigation water demand” for the proposed subdivision the civil engineer and the geotechnical engineer has provided the following pre and post development data:

ABC Subdivision

Pre Development

		Basin 1	**Basin 2**	**Basin 3**	**Total**
Soil Class	**Cover Type**	**Area (acres)**	**Area (acres)**	**Area (acres)**	**Area (acres)**
A	Pasture	41.36	6.19	2.06	49.61
A/D	Forest/Wetland - Good	4.69	5.90	0.00	10.59
A/D	Water	0.00	1.80	0.00	1.80
				Total	**62.00**

Download the above spreadsheet at:
http://www.suncam.com/authors/026Andreyev/209/E3a.zip

ABC Subdivision

Post Development

Basin	Driveways	Housing				Roadway		Other Impervious	Pond	Pervious GWT>5 ft	Pervious GWT<5 ft
		65' Lots	75' Lots	Rooftops Area	Paved/Slab Area	Length	Area	Area	Area	Area	Area
(#)	(#)	(#)	(#)	(ac)	(ac)	(50' ROW)	(ac)	(ac)	(ac)	(ac)	(ac)
1	38	12.0	28.0	2.58	2.70	1,645	1.17	0.50	2.85	7.33	2.05
2	113	89.0	1.0	5.38	5.80	5,840	4.16	0.00	2.27	13.24	3.42
3	4	4.0	0.0	0.24	0.24	400	0.28	0.00	0	0.35	0.25
4	0	13.0	8.0	1.31	1.07	0	0.00	0.00	0	3.35	0.74
5	0	0.0	0.0	0.00	0.00	0	0.00	0.00	0	0.00	0.72
	155	118.0	37.0	9.51	9.81	7,885	5.61	0.50	5.12	24.27	7.18

NOTES:

1. Driveways are assumed as 600 sq-ft of impervious area.
2. 65' lots are assumed to have 2,600 sq-ft of rooftops and 2,050 sq-ft of other impervious area.
3. 75' lots are assumed to have 2,900 sq-ft of rooftops and 2,500sq-ft of other impervious area.
4. 50' ROW are assumed to have 31 ft of impervious, including 24 ft of pavement, 2 ft curb & gutter, and 5 ft sidewalk.
5. Ammenity Center was included as Other Impervious.

Download the above spreadsheet at:
http://www.suncam.com/authors/026Andreyev/209/E3b.zip

From the data provided above, the evaporation and evapotranspiration rates for pre and post development surfaces were estimated from Dr. Eslinger's study as follows:

Surface Type	Annual Evap./ET
Pasture on upland areas, deep groundwater	36
Forested Wetland and low areas around the wetlands	51
Open Water (pond/lake)	52
Rooftops	10
Paved Surfaces	12
Landscaped & grass covered areas, groundwater depth > 5 feet	37
Landscaped & grass covered areas, groundwater depth < 5 fee	41

Using these values the following "balanced irrigation water demand" calculations can be made (for the post development under "Other Impervious" assume 0.15 acre of rooftops and 0.35 acre of paved areas). The conversion from acres to square feet is:
1 acre=43,560 square feet:

	Area (ft^2)	Annual Water Sources (in/yr)	Annual Water Sources (ft^3/yr)	Annual Water Losses (in/yr)	Annual Water Losses (ft^3/yr)	Annual Net Recharge (ft^3/yr)
Existing Condition						
Rainfall	2,700,720	49.50	11,140,470.00			
Pasture in sandy soil (SCS Soil type A)	2,161,012			36.00	6,483,034.80	
Forested Wetland in good condition	461,300			51.00	1,960,526.70	
Open Water (Pond/Lake)	78,408			52.00	339,768.00	
Net Recharge to Aquifer (on-site and off-site)						2,357,140.50
Post Construction Condition						
Rainfall	2,700,720	49.50	11,140,470.00			
Rooftops	420,790			10.00	350,658.00	
Paved Surfaces	686,941			12.00	686,941.20	
Open Water (Pond/Lake)	229,561			52.00	994,765.20	
Landscaped/grass cover GWT > 5 feet	1,082,030			37.00	3,336,260.40	
Landscaped/grass cover GWT < 5 feet	281,398			41.00	961,441.80	
Net Recharge to Aquifer (on-site and off-site)						4,810,403.40
Balanced Irrigation Water Available (Post-Pre)						2,453,262.90
Maximum Irrigated Surface (assume 36 in/yr)	817,754					

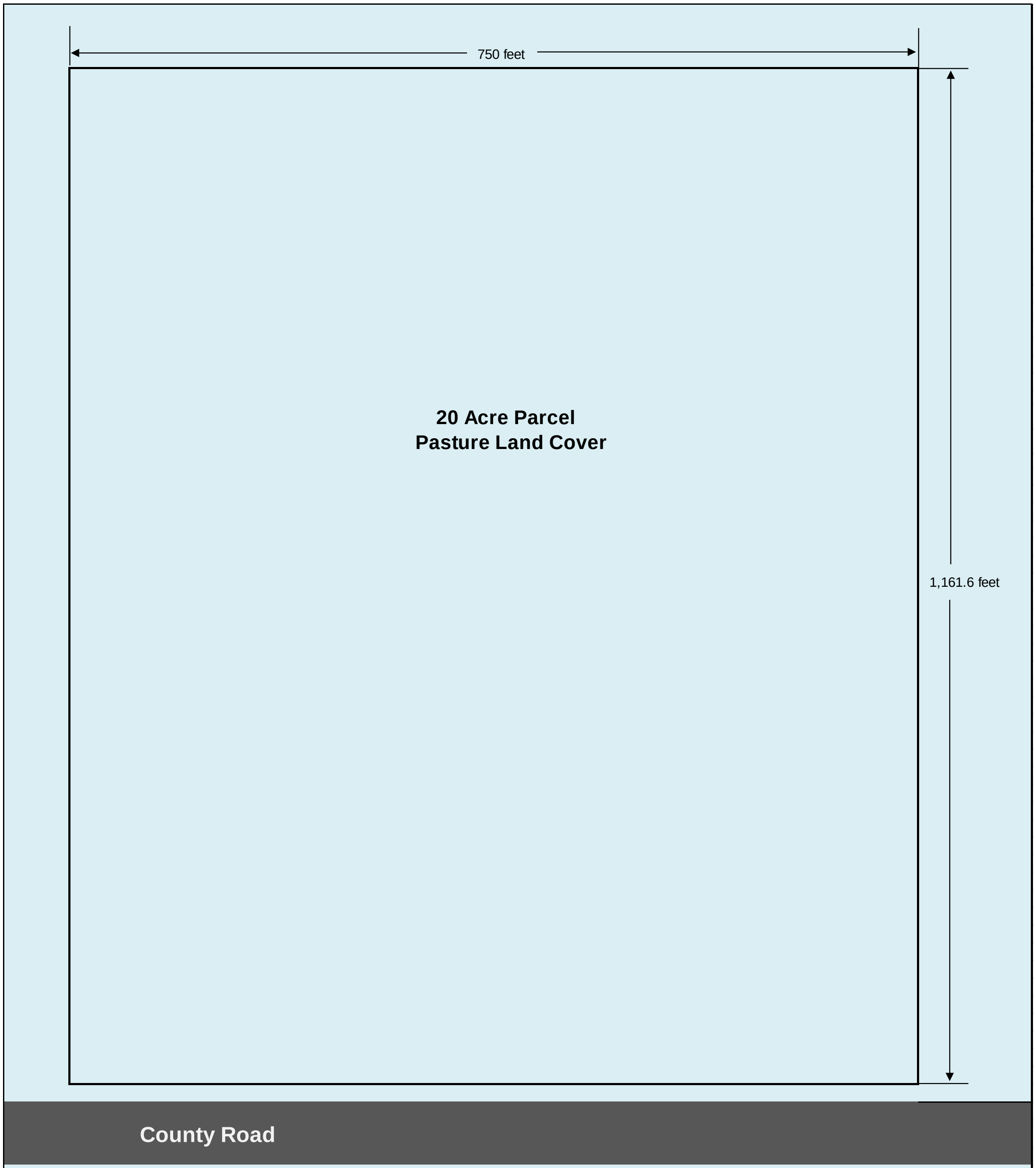
The ABC subdivision has a total of 155 lots plus an amenity center. Allowing about 4,500 ft^2 of irrigated surface at the amenity center, the remaining calculated irrigated surface can be divided by the total number of lots to estimate the average irrigated surface for each lot. Converting the remaining balanced maximum irrigated surface area (817,754 – 4,500 = 813,254) into the 155 lots results in a maximum irrigated surface area of 5,246.8 ft^2 per lot or about 0.12 acres per lot. This area exceeds the needed landscaped and irrigated areas of the lots for this subdivision. The total lot sizes in this subdivision range from about 7,500 ft^2 to a maximum of 9,000 ft^2 and the remaining pervious areas of the lot (excluding house, driveway, sidewalk and other paved surfaces) will be less than 50% of the total area. Therefore, the calculated balanced irrigation water allowance exceeds the needed water demand. For this subdivision, the allowable irrigated area can be the entire remaining pervious surface of each lot.

The resulting calculated high “maximum irrigated surface area” for this subdivision is due to the high density of the lots and the large percentage of impervious surfaces created by the development. The impervious surfaces reduce the evapotranspiration losses significantly, thus creating a net gain in the water sources for the drainage basin (closed drainage basin).

Example 4

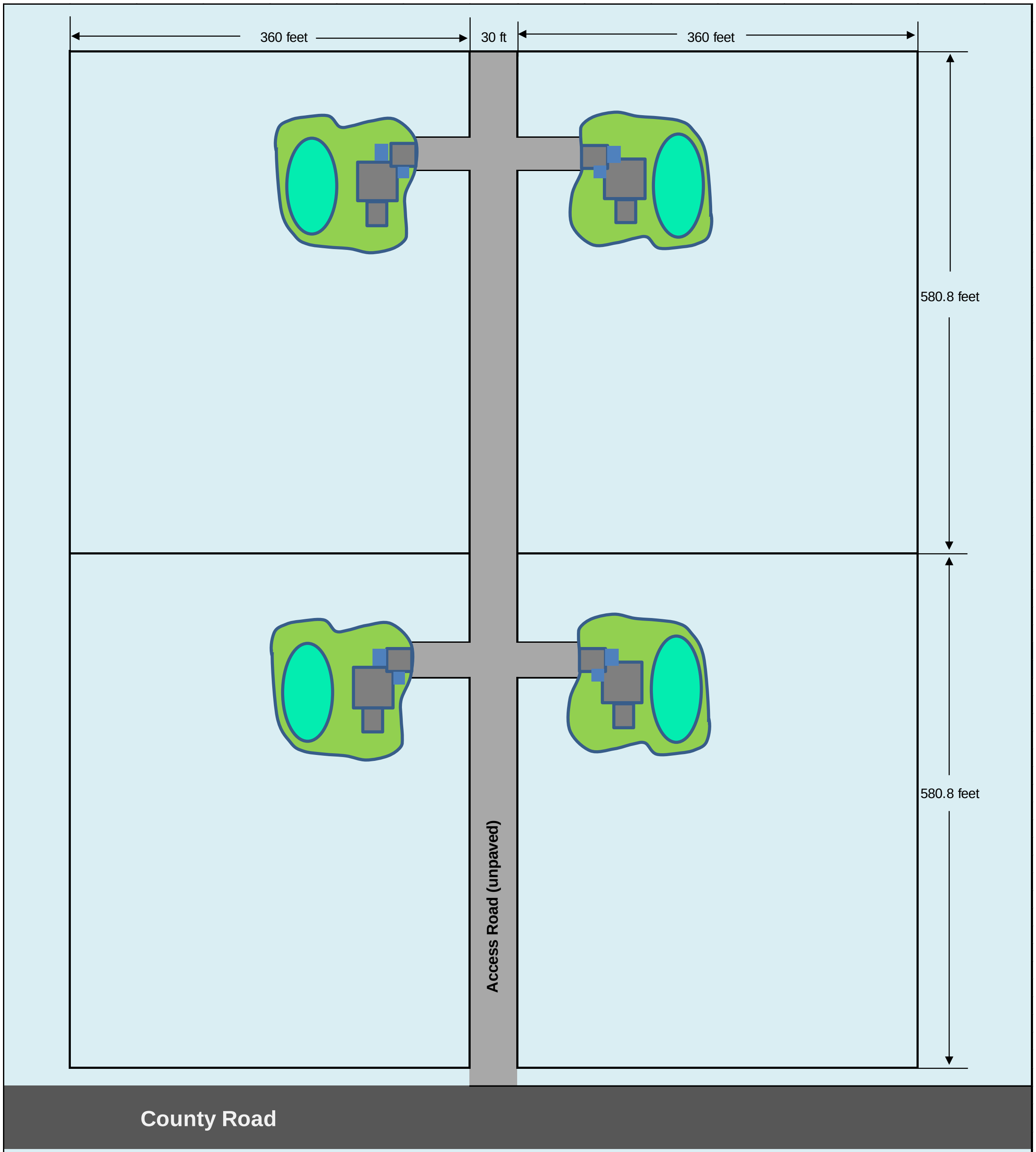
For this example we will evaluate a small development of 4 lots located in a low density land use zoning, typical of rural areas around large cities and towns in Florida. Typically, the land use codes in rural areas restrict subdivision of property to 5 acres per lot. This type of zoning implies that if the density is reduced to these levels, then the impacts to the environment and natural resources will be negligible.

The following 20 acre parcel and the 4 lot layout of a rural area subdivision is typical, where a property owner that has 20 acres of land subdivides it into 4 lots, 5-acres each, and develops the land into 4 residential houses with a septic tank and drainfield and a shallow aquifer water well for potable supply and irrigation.



Typical 20 Acre Parcels to be Subdivided into 4 Lots

Total Parcel Area 871,200 ft^2 = 20 Acres
Unimproved Pasture Land with average depth to groundwater table = 3 feet
Very Few Trees Across the Property



Typical Layout for 4 Lot Subdivision (5-acre lots)

Total Lot Area	**871,200** ft^2
▬	1,800 ft^2 per lot under roof (house, garage, other)
🟦	220 ft^2 per lot concrete pads & entry ways
🟩	6,000 ft^2 per lot excavated pond (unlined open water)
●	15,000 ft^2 per lot landscaped area with trees, shrubs and grass cover

This development is located in Lake County (central Florida). The setting of the site is sandy soil with relatively shallow groundwater conditions. Historically, the property has been used as pasture land and has been cleared of most trees (also typical for large portions of Lake County). From available data (USGS quadrangle maps and SCS soil survey data), the following general site conditions have been estimated:

1. The land is located in a closed drainage basin area, typical of Lake County.
2. Some off site runoff may occur during heavy rainfall events, but it is retained within the drainage basin in lakes and dry depressions.
3. The soils consist of mostly fine sand and silty fine sand. Some clayey sand may exist below the sandy surface.
4. Groundwater was estimated at an average depth of 3 feet below ground surface from the SCS soil survey data/
5. The existing soil cover is mostly pasture with occasional trees, very few trees.
6. Average annual rainfall for this area is estimated at 48.5 inches.

From the data provided above, the evaporation and evapotranspiration rates for pre and post development surfaces were estimated from Dr. Eslinger's study as follows:

Surface Type	**Annual Evap./ET**
Pasture land with sandy soil and GWT at about 3 feet	37
Open Water (pond/lake)	52
Rooftops	10
Paved Surfaces	12
Landscaped areas with trees & grass cover	40

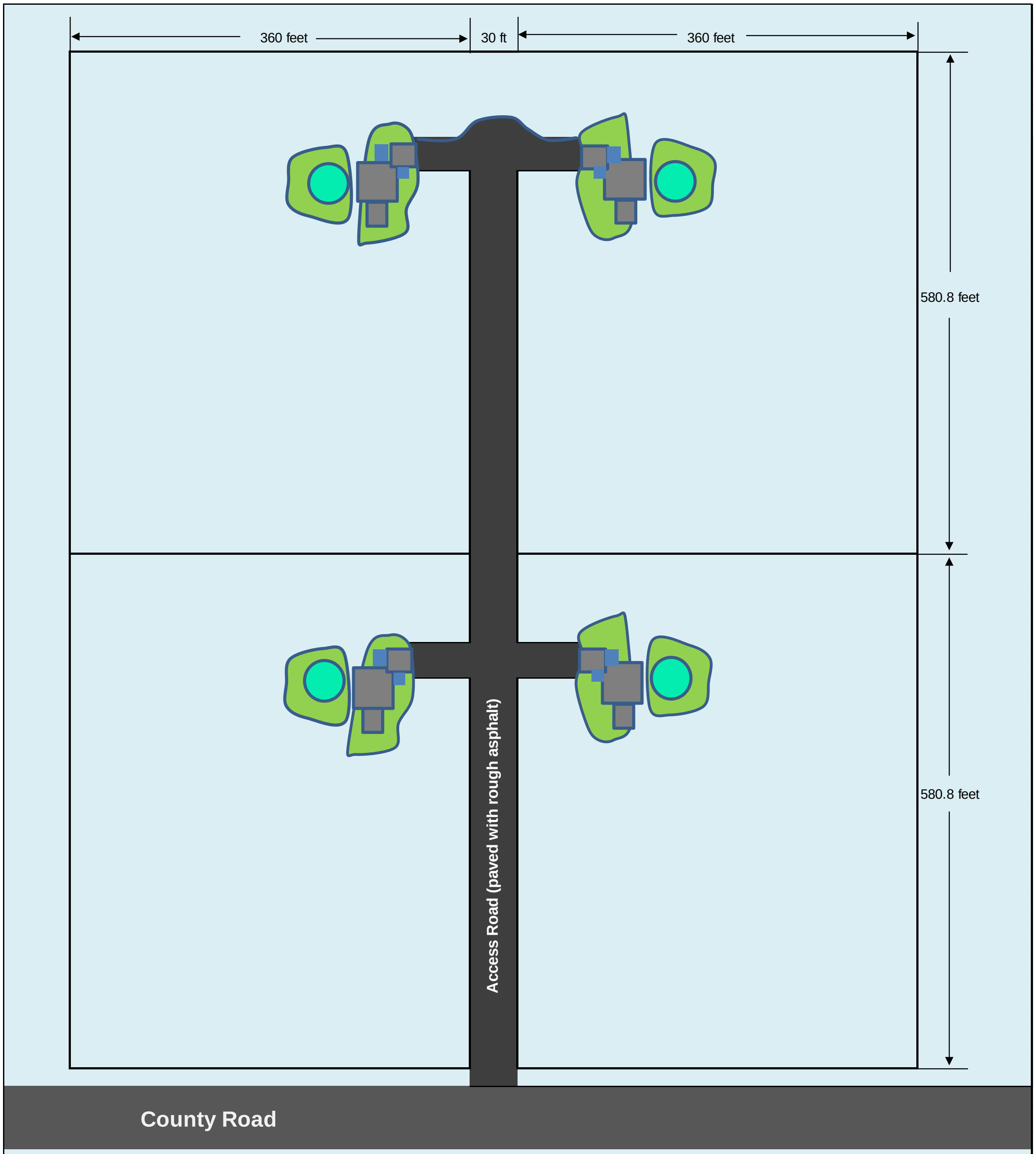
Using these values the following "balanced irrigation water demand" calculations were made for the combined 4 lots of the original 20 acre parcel. The conversion from acres to square feet is: **1 acre=43,560 square feet**:

	Area (ft^2)	Annual Water Sources (in/yr)	Annual Water Sources (ft^3/yr)	Annual Water Losses (in/yr)	Annual Water Losses (ft^3/yr)	Annual Net Recharge (ft^3/yr)
Existing Condition						
Rainfall	871,200	48.50	3,521,100.00			
Pasture Land with average GWT = 3 feet	871,200			37.00	2,686,200.00	
Net Recharge to Aquifer (on-site and off-site)						834,900.00
Post Construction Condition						
Rainfall	871,200	48.50	3,521,100.00			
Rooftops	7,200			10.00	6,000.00	
Paved Surfaces	880			12.00	880.00	
Pond (open water)	24,000			52.00	104,000.00	
Landscaped areas with trees and grass cover	60,000			40.00	200,000.00	
Pasture Land with average GWT = 3 feet	779,120			37.00	2,402,286.67	
Net Recharge to Aquifer (on-site and off-site)						807,933.33
Balanced Irrigation Water Available (Post-Pre)						-26,966.67
Maximum Irrigated Surface (assume 34 in/yr)	0					

As shown in the calculation table above, the net recharge to the aquifer is less in the post developed condition. As a result the calculated "balanced irrigation water available" is a negative number. This indicates that no balanced irrigation water is available for this site and the landscaped areas should be installed without any irrigation. Any groundwater withdrawal for irrigations will create a further imbalance in the aquifer recharge at the 20 acre parcel.

It is interesting to note in this example that a low density development can actually reduce net recharge and create a condition not favorable to landscaping and irrigation. In contrast, a high density subdivision presented in Example 3 with 155 tightly packed lots produce excess water sources for irrigation. That is because the high density developments provide large impervious surfaces where the ET is reduced significantly conserving more water for the area, provided of course that the runoff water from impervious surfaces is captured within the drainage basin and not loss to rivers or oceans without beneficial recharge.

A design modification can be made for the 4-lot development in Example 4 where some irrigation water could be generated to allow irrigation of a modest landscaped area. The two components that generally increase water sources in these analyses are the rooftops and paved surfaces. The losses of water for these lots come mostly from the excavated ponds in the back of each house, where the evaporation rate is higher than under existing pasture land use conditions. So, we could either reduce the size of the ponds or eliminate them altogether and perhaps increase paved surface by paving the access road and driveways. For the revised layout of the 4 lots, we will reduce the proposed pond areas to 50 ft x 50 ft (2,500 ft^2), and pave the entrance road and the driveways and reduce the landscaped area to about 5,000 ft^2 around the front of the houses and around the pond areas. The following revised plans will be used for the revised analysis:



Typical Layout for 4 Lot Subdivision (5-acre lots)

Total Lot Area **871,200** ft^2

▬ 1,800 ft^2 per lot under roof (house, garage, other)
▬ 220 ft^2 per lot concrete pads & entry ways
▬ 32,000 ft^2 of paved road & driveways (rough asphalt pavement)
▬ 2,500 ft^2 per lot excavated pond (unlined open water)
⬬ 5,000 ft^2 per lot landscaped area with trees, shrubs and grass cover

For the revised 4-lot layout and changes in development provided on the plan above, the evaporation and evapotranspiration rates for pre and post development surfaces were estimated as follows:

Surface Type	Annual Evap./ET
Pasture land with sandy soil and GWT at about 3 feet	37
Open Water (pond/lake)	52
Rooftops	10
Paved Surfaces	12
Paved access road & driveway with rough asphalt pavement	16
Landscaped areas with trees & grass cover	40

The slightly higher rate of water loss (ET) from the paved access road is due to the typical rough pavement type of construction observed in such developments, primarily to reduce the cost of construction. The rougher surface will tend to retain more rain water after each storm event and allow it to evaporate from the surface (surface abstraction effects). Using these values the following “balanced irrigation water demand” calculations were made for the revised 4 lots rural development:

	Area (ft^2)	Annual Water Sources (in/yr)	Annual Water Sources (ft^3/yr)	Annual Water Losses (in/yr)	Annual Water Losses (ft^3/yr)	Annual Net Recharge (ft^3/yr)
Existing Condition						
Rainfall	871,200	48.50	3,521,100.00			
Pasture Land with average GWT = 3 feet	871,200			37.00	2,686,200.00	
Net Recharge to Aquifer (on-site and off-site)						834,900.00
Post Construction Condition						
Rainfall	871,200	48.50	3,521,100.00			
Rooftops	7,200			10.00	6,000.00	
Paved Surfaces	880			12.00	880.00	
Pond (open water)	10,000			52.00	43,333.33	
Paved access road & driveways (rough asphalt cover)	32,000			16.00	42,666.67	
Landscaped areas with trees and grass cover	20,000			40.00	66,666.67	
Pasture Land with average GWT = 3 feet	801,120			37.00	2,470,120.00	
Net Recharge to Aquifer (on-site and off-site)						891,433.33
Balanced Irrigation Water Available (Post-Pre)						56,533.33
Maximum Irrigated Surface (assume 32 in/yr)	21,200					

For this revised design parameters, just enough balanced irrigation water is generated to provide for the reduced landscaped areas at the 4 lots. The landscaped area selected for this plan was 5,000 ft^2 per lot or a total of 20,000 ft^2. The calculated total maximum irrigated surface area was 21,200 ft^2. Therefore, if these 4 lots were to be developed for the "balanced irrigation water" scenario, then the revised design parameters above should be imposed.

Summary

An analysis of the water sources and water losses from any area of concern can be made using the presented balanced irrigation water demand approach. This course was designed specifically to analyze the balanced irrigation water demands for a single house or for multiple houses of residential developments. However, the methodology can be applied to any other project or natural system to assess the effects of changes made at the surface, or subsurface, that creates an imbalance of water gains, losses or aquifer recharge.

The introductory method presented in this course was made simple on purpose and is limited to calculating the beneficial effects of various land uses or land surface covers that produce additional water through increased runoff and reduced rates of evaporation and evapotranspiration. It is also important to note that these beneficial effects are the most applicable to areas with closed drainage basins, where all runoff either recharges back into the aquifer at the investigated site or within the localized regional drainage basin. However, this analysis can also be extended to the drainage basin with some discharge to river, creeks or oceans, as long as, the amount of annual discharge can be quantified and incorporated into the analysis.

The balanced irrigation water demand analysis presented in this course can be used as a first brush approach to assess the potential of a particular house, building or subdivision to affect the net aquifer recharge and thus providing a limit to the amount of irrigation water that should be used under a balanced aquifer recharge scenario.

The water balance analysis can be further expanded to include the effects of the irrigation water application itself, the effects of septic tank recharge (especially if the potable water is from a source outside the drainage basin), base surface flow volumes to assure viable downstream conditions, deeper aquifer recharge components, and a long list of other parameters that can be incorporated into the water balance. However, an all-inclusive level of water balance analysis is beyond the intended scope of this course and will be presented in a separate "advanced" course in the future.

It is the author's sincere hope that this introductory course on balanced irrigation water demand methods will spark the interest of readers and lead to serious discussions among various interested parties, including engineers, geologist, developers, planners, regulators, politicians and others. The long term goal would be to expand these discussions, conduct further research and develop a comprehensive methodology that can be incorporated into the regulatory framework, where the future of Florida water use is conducted in a holistic water balance approach to protect the water resources at the planning and design levels.

One of the aspects of this approach will no doubt necessitate development of a consistent methodology to design all future development with retention ponds that not only retain and attenuate a design storm events, but are sized to achieve a long term water balance in terms of off-site discharge (outside the drainage boundaries) to preserve annual average water retention within the drainage basins. This will necessitate the development of a methodology to analyze daily storm events for periods of a year or more to match the post development volumetric discharge to the pre development values. The end result of this type of analysis will provide an estimate of the maximum balance irrigation water available for the project while maintaining all natural features of the land (recharge characteristics, wetlands and other surface waters, base and off-site flows) within each drainage basin.