Full Spectrum Detention and Water Rights

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Overview of Presentation

- Objectives and Approach
- SWMM Water Balance Modeling
- Water Rights Analysis
- Conclusions

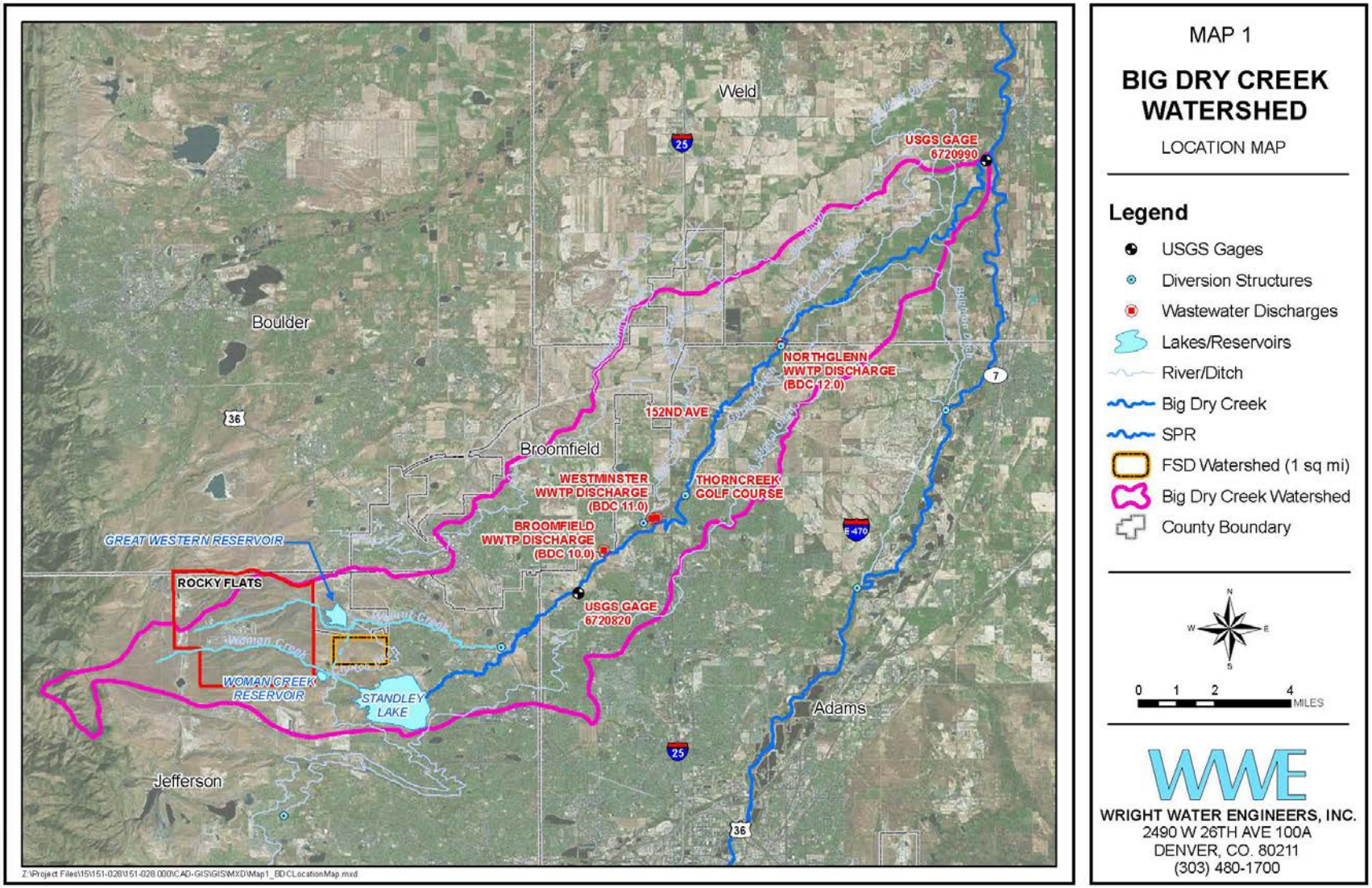
OBJECTIVES & APPROACH

Colorado Revised Statute (CRS) §37-92-602 (8)

- UDFCD legislative effort in 2015 session
- Provides legal protection for stormwater detention and infiltration facilities meeting criteria:
  1. Owned or operated by a governmental entity or subject to oversight by governmental entity (e.g., required under MS4 permit)
  2. Continuously releases or infiltrates at least 97% of all runoff from a rainfall event < = 5-year storm within 72 hours after the end of the event
  3. Continuously releases or infiltrates as quickly as practicable, but in all cases releases or infiltrates at least 99% of the runoff within 120 hours after the end of events > = 5-year storm
  4. It operates passively and does not subject the stormwater runoff to any active treatment process
  5. If located in Fountain Creek watershed (tributary to the Arkansas River), facility must be required by or operated in compliance with MS4 permit

Objectives

- Conduct long-term water balance analysis to quantify changes to the quantity and timing of water available to water rights users.
- Quantification of water balance differences between undeveloped, developed, and developed with FSD.
- Evaluation of changes in balance (evaporation, ET, infiltration, surface runoff) for varying levels of imperviousness.
- Examine effects of timing of runoff/releases from FSD facilities.
- Evaluate effects on downstream water users.



MAP 1

BIG DRY CREEK WATERSHED

LOCATION MAP

Legend

- USGS Gages
- Diversion Structures
- Wastewater Discharges
- Lakes/Reservoirs
- River/Ditch
- Big Dry Creek
- SPR
- FSD Watershed (1 sq mi)
- Big Dry Creek Watershed
- County Boundary

N W E S

0 1 2 4 MILES

WRIGHT WATER ENGINEERS, INC.
2490 W 26TH AVE 100A
DENVER, CO. 80211
(303) 480-1700

Approach

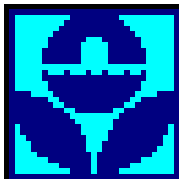
- Combine hydrology model (SWMM) with water rights model (spreadsheet)
- Model “typical” developments scenarios for hypothetical watershed (range of imperviousness)
- UDFCD spreadsheets for conceptual FSD sizing
- Water Rights model to assess downstream effects of SWMM scenarios

Watershed Parameters

- 1-square mile “typical” watershed
- Imperviousness 2%, 20%, 35%, 50%, 65%, 80%
- Sub-basin parameters from 2006 Big Dry Creek Northern Tributaries OSP
- Horton infiltration using parameters from USDCM

Climate Data

- Hourly Precipitation
- Daily Min and Max Temperatures
- Wind Speed
- Evaporation/ET calculated by model



SWMM

Aquifer Parameters

- Porosity
- Field Capacity
- Wilting Point
- Upper/ lower zone water availability for ET

Daily Time Series Output from SWMM

- Outflow
- Evaporation/ET
- Storage

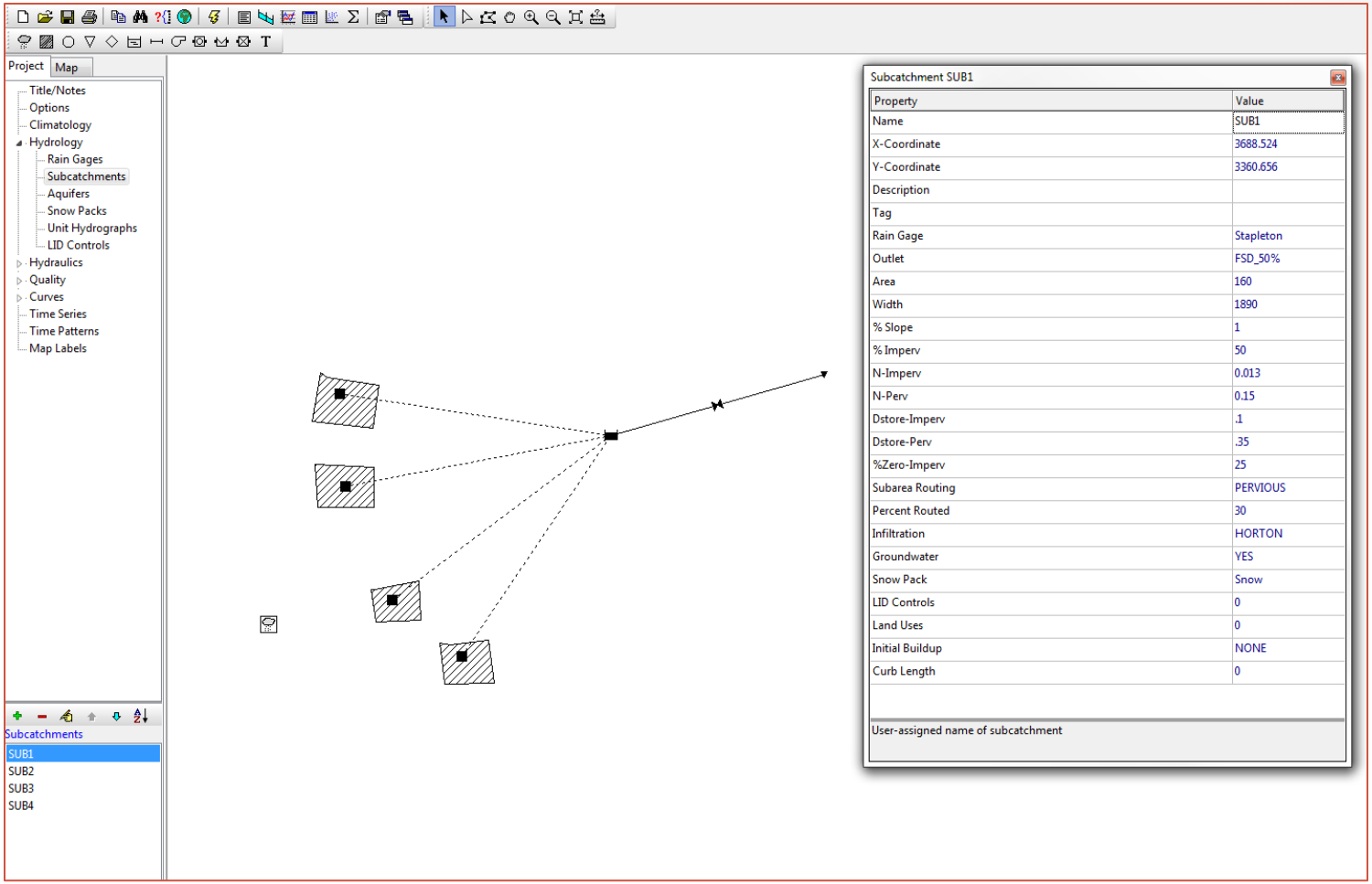
Water Rights Accounting

- Streamflow
- Diversion Records
- Return Flows
- Calls

Water Rights Spreadsheet

Output from Water Rights Spreadsheet

Water shortage or water surplus



SWMM WATER BALANCE MODELS

Fundamental Model Assumptions

- One square mile watershed (major drainage scale, typical of large scale development projects)
  - Use Big Dry Creek Northern Tributaries OSP as starting point for “typical” model parameterization
  - 160 acre sub-basins (similar to UDFCD master plan modeling)
  - Assume directly tributary to waterway
- Imperviousness varied from undeveloped (2%) to dense development (80%)
- Climate data (hourly rainfall, temperature, wind speed, etc.) from NOAA GHCN-D climate data files

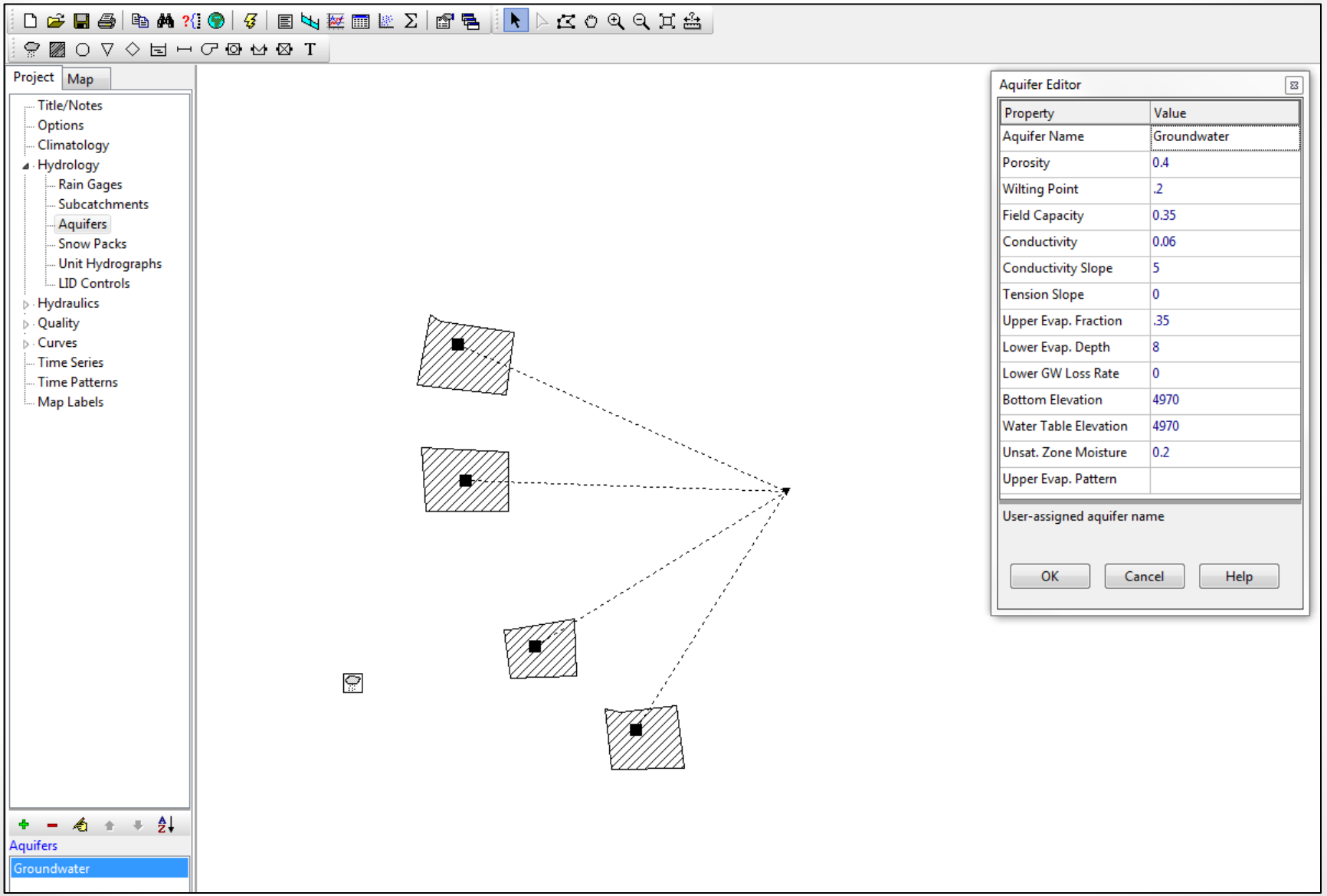
Fundamental Model Assumptions (cont.)

- Horton Loss parameters (guidance from USDCM), assume HSG C.
- Evaporation occurs from surface water (e.g. depression storage, runoff).
- Shallow aquifer beneath site – fraction of water in upper soil zone is available for ET between events:
  - Aquifer is “bucket” and change in aquifer storage represents shallow (tributary) groundwater recharge or depletion
  - Aquifer ET parameters “calibrated” for undeveloped scenario to yield results where ET ~ PET for native plants, with infrequent runoff.
- Snowmelt incorporated for runoff timing effects – not a sensitive parameter.

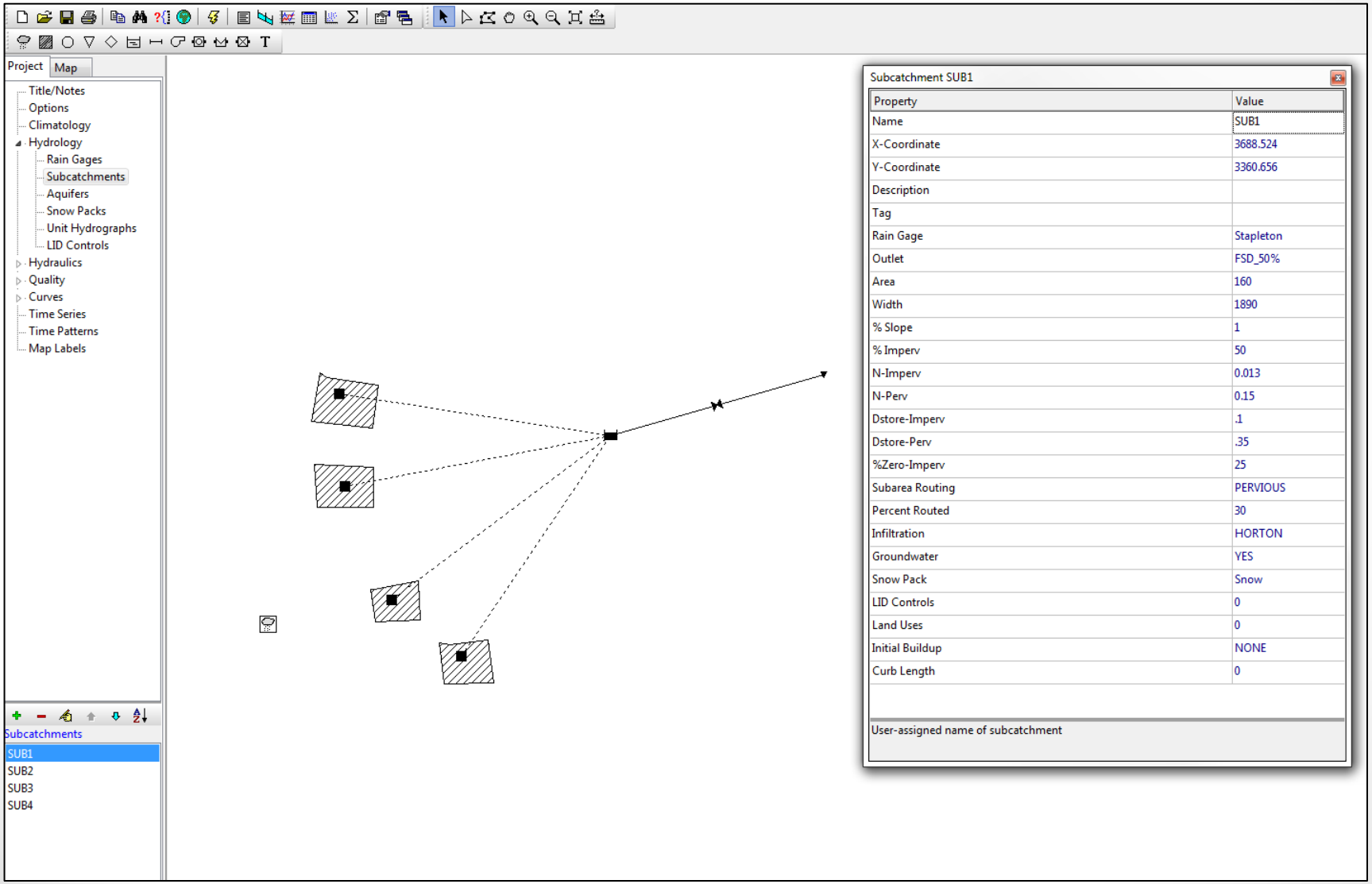
Fundamental Model Assumptions (cont.)

- Assumes dry land/native land use prior to development.
- Additional irrigation water not accounted for in model:
  - Model provides capabilities to evaluate alternate scenarios, including return flows from irrigated land; however, scope of this assessment did not include irrigation.
- Results from 1 square mile are scalable to larger areas.

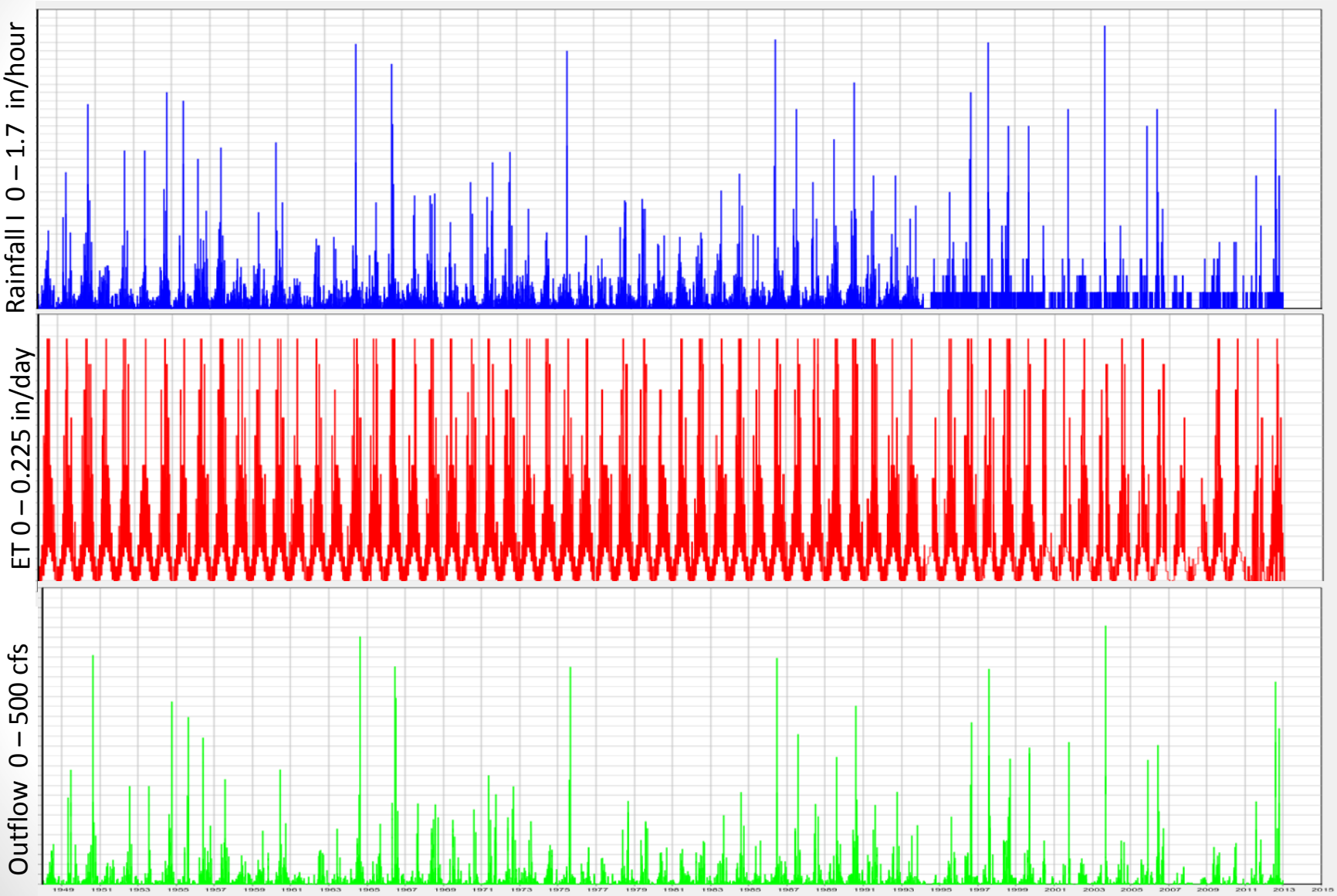
SWMM Layout for Model with No FSD



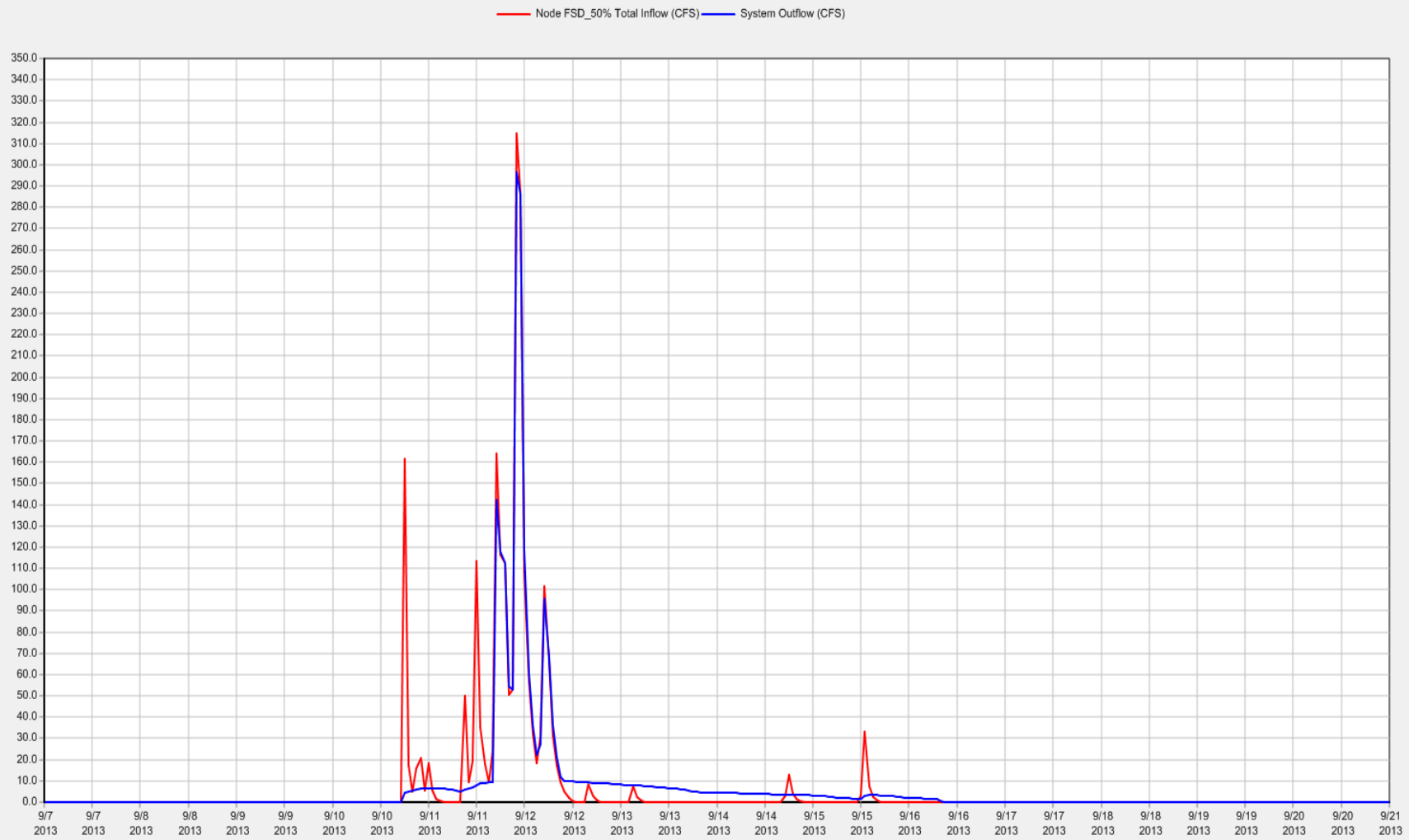
SWMM Model Layout with FSD



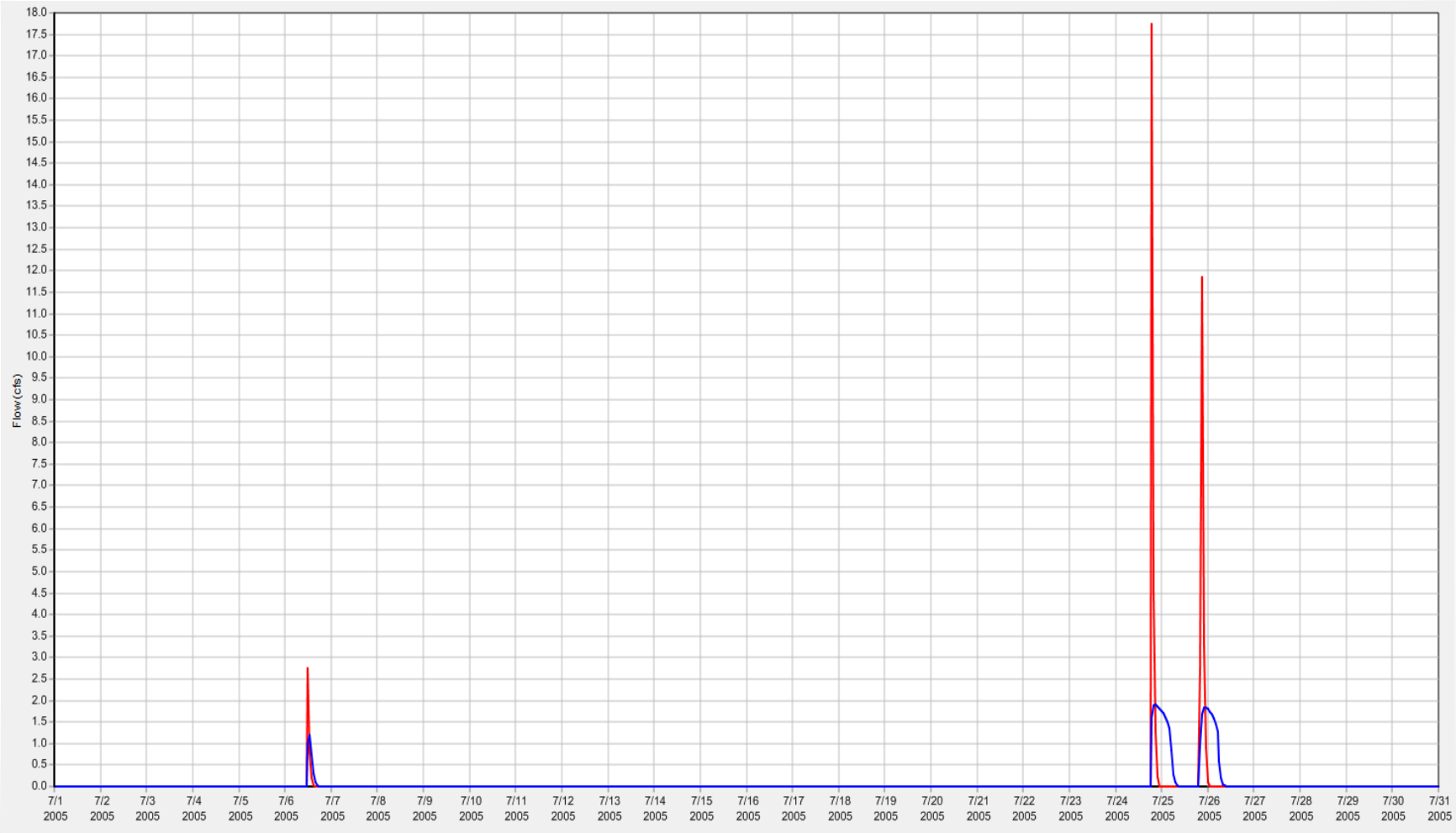
Precipitation, ET & System Outflow, 1949 - 2013

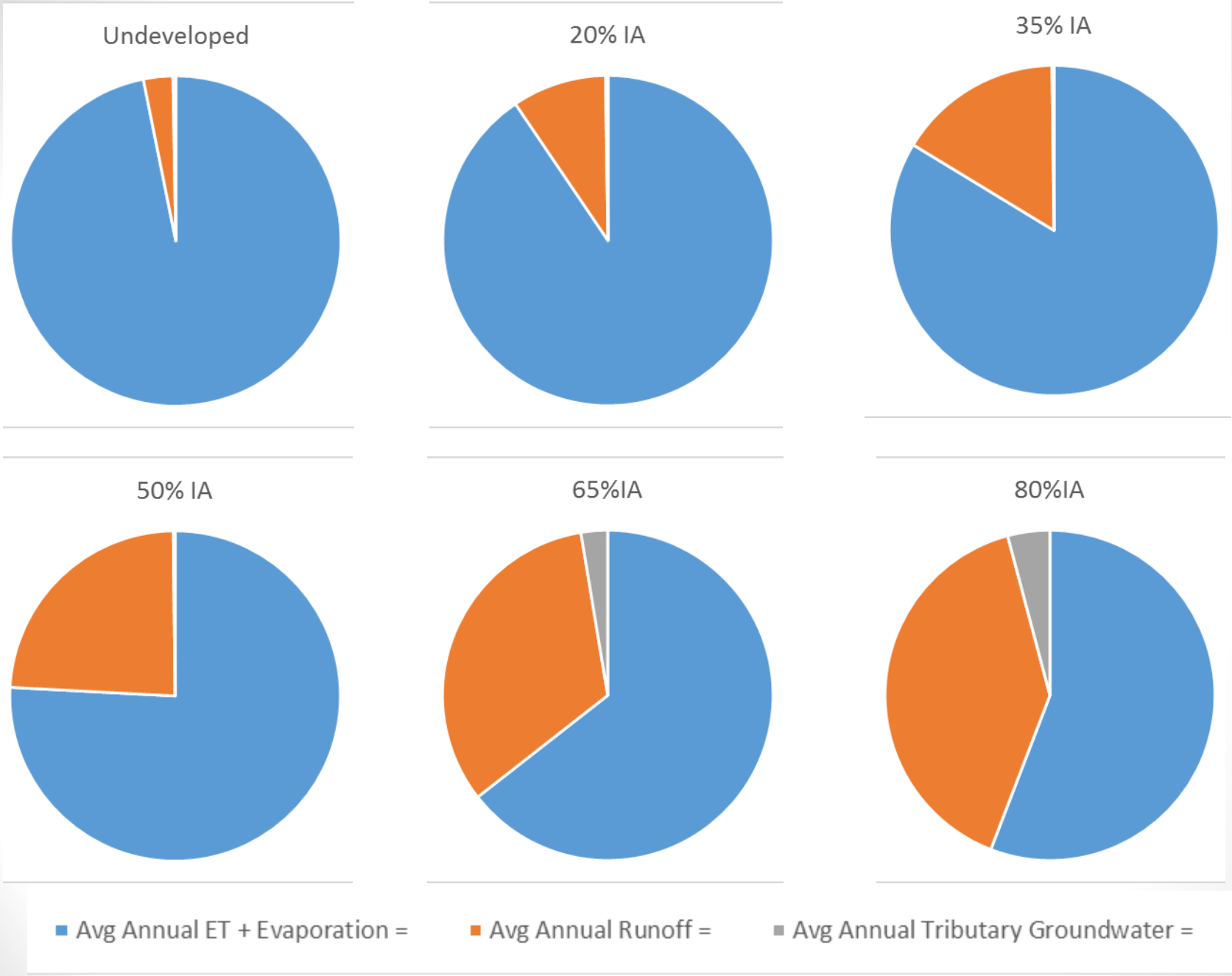


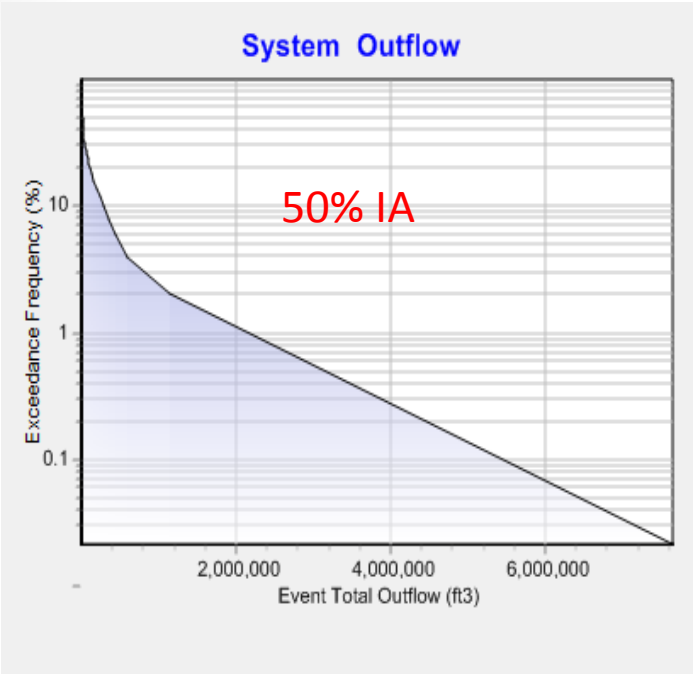
FSD Inflow and Outflow September 2013, 50% IA

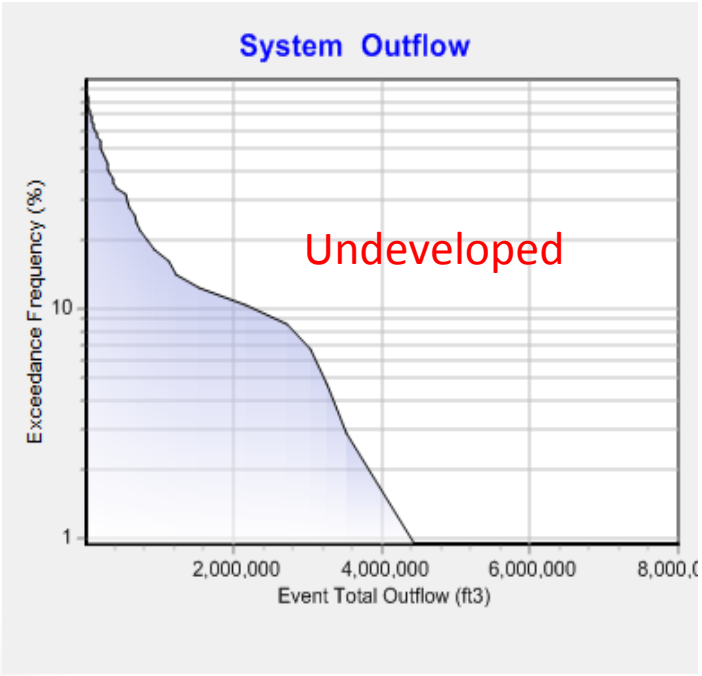


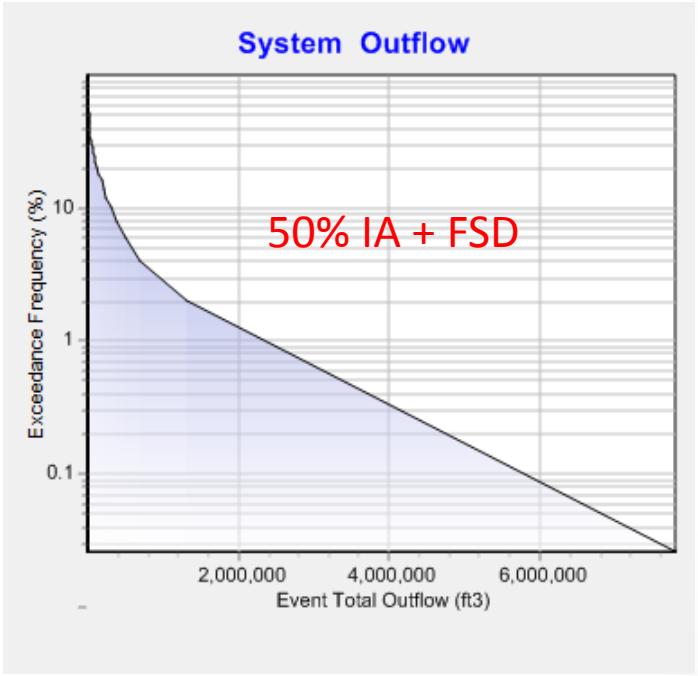
Modeled FSD Inflow and Outflow, July 2005, 50% IA



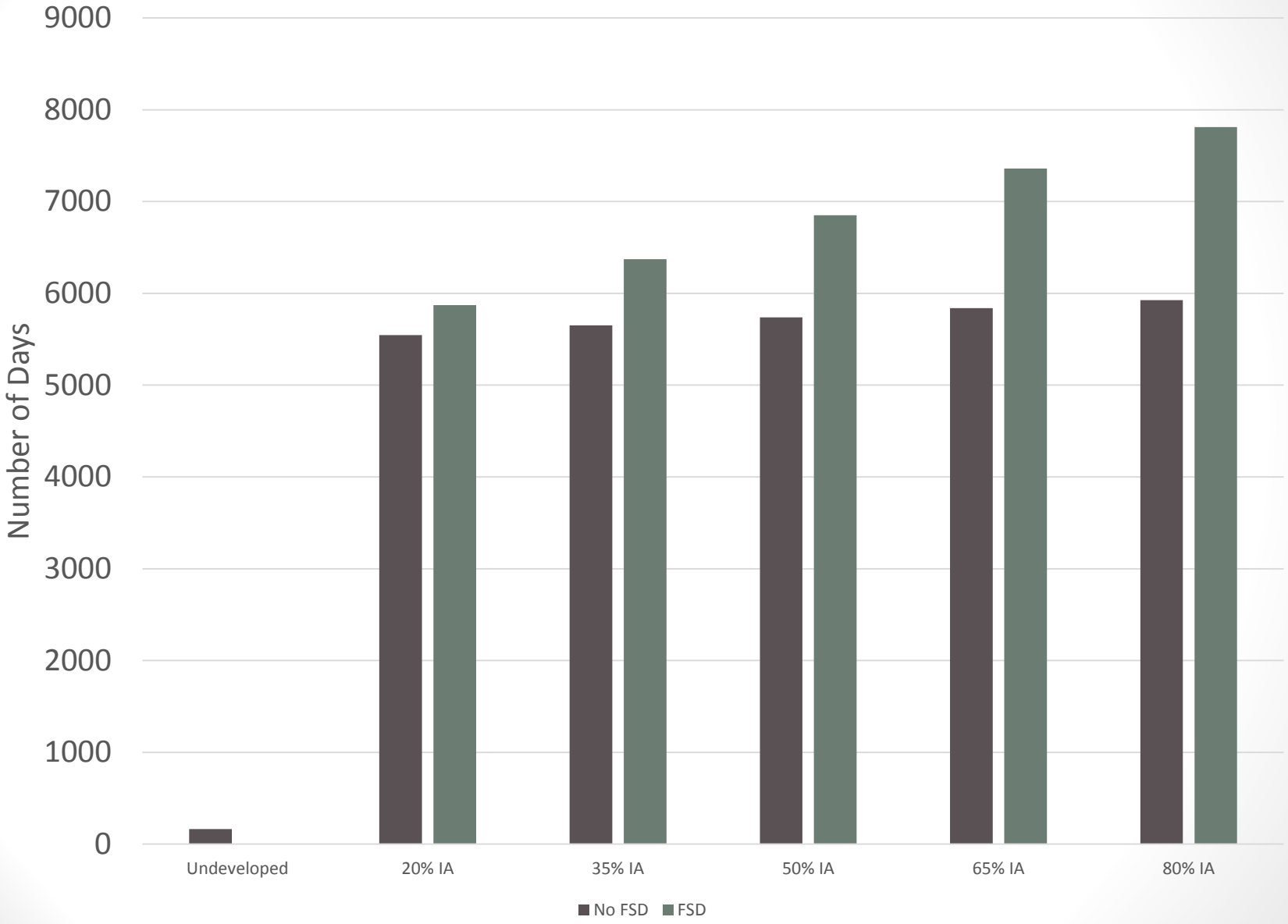

Undeveloped
20% IA
35% IA
50% IA
65%IA
80%IA
Avg Annual ET + Evaporation =
Avg Annual Runoff =
Avg Annual Tributary Groundwater =


System Outflow
50% IA
Exceedance Frequency (%)
10
1
0.1
2,000,000
4,000,000
6,000,000
Event Total Outflow (ft3)

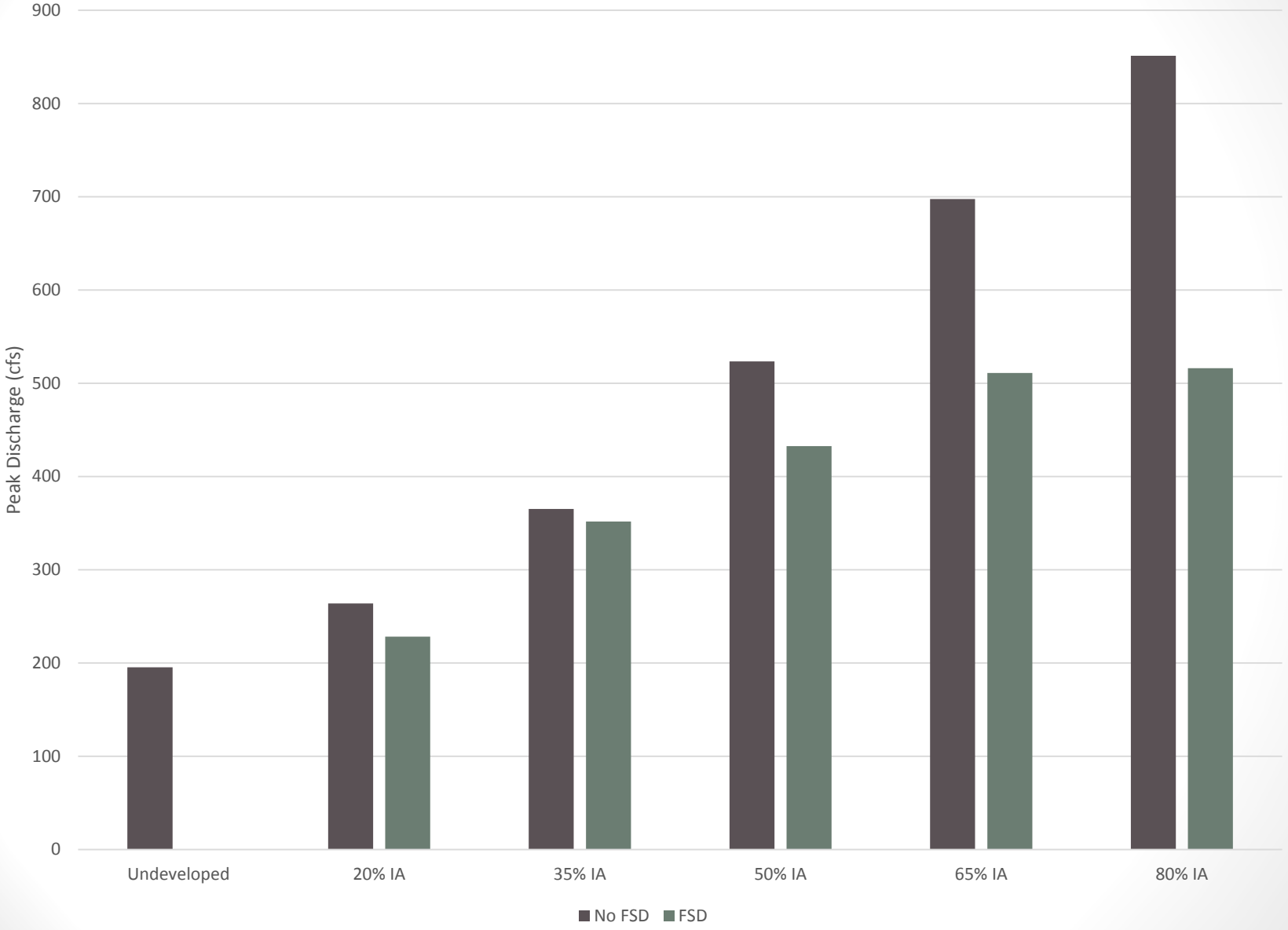

System Outflow
Undeveloped
Exceedance Frequency (%)
10
1
2,000,000
4,000,000
6,000,000
8,000,(
Event Total Outflow (ft3)


System Outflow
50% IA + FSD
Exceedance Frequency (%)
10
1
0.1
2,000,000
4,000,000
6,000,000
Event Total Outflow (ft3)

Number of Days with System Outflow



Peak Outflow Rates with and without FSD



Results – Precipitation & Outflow

Precipitation											
Variables	**Undev**	**20% IA**	**20% IA + FSD**	**35% IA**	**35% IA + FSD**	**50% IA**	**50% IA + FSD**	**65% IA**	**65% IA + FSD**	**80% IA**	**80% IA + FSD**
Number of Events	4931	4931	4931	4931	4931	4931	4931	4931	4931	4931	4931
Mean Daily Precip (in)	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Max Daily Precip (in)	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.39

System Outflow											
Variables	**Undev**	**20% IA**	**20% IA + FSD**	**35% IA**	**35% IA + FSD**	**50% IA**	**50% IA + FSD**	**65% IA**	**65% IA + FSD**	**80% IA**	**80% IA + FSD**
Number of Events	163	5545	5871	5652	6372	5738	6852	5838	7361	5927	7812
Mean Daily Outflow (cfs)	12.2	1.3	0.6	2.1	0.9	3.0	1.2	3.9	1.4	4.4	1.7
Peak Daily Outflow (cfs)	196	264	228	365	352	523	433	697	511	851	516
Mean Daily Outflow (ac-ft)	8.9	0.9	0.7	1.5	1.2	2.2	1.7	2.9	2.2	3.5	2.6
Max Daily Outflow (ac-ft)	77	94	72	113	96	129	102	144	125	158	133

Results – Evaporation/ET and Storage

Evaporation											
Variables	**Undev**	**20% IA**	**20% IA + FSD**	**35% IA**	**35% IA + FSD**	**50% IA**	**50% IA + FSD**	**65% IA**	**65% IA + FSD**	**80% IA**	**80% IA + FSD**
Number of Events	20689	22032	22833	22443	22443	23529	23529	23707	23707	23707	23707
Daily Mean Evap (in)	0.043	0.036	0.036	0.042	0.042	0.038	0.038	0.038	0.038	0.039	0.039
Peak Daily Evap (in)	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228	0.228

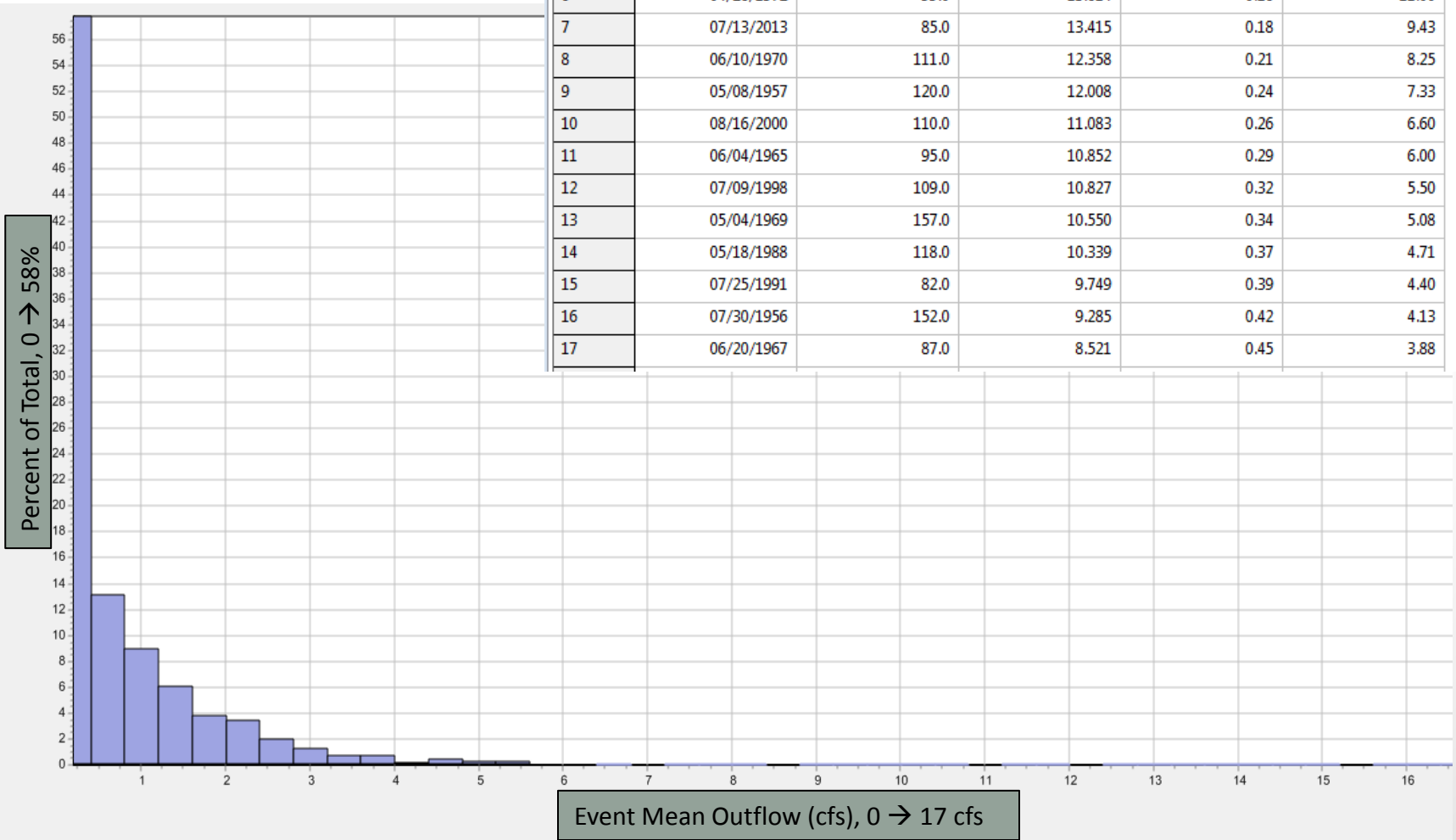
Storage											
Variables	**Undev**	**20% IA**	**20% IA + FSD**	**35% IA**	**35% IA + FSD**	**50% IA**	**50% IA + FSD**	**65% IA**	**65% IA + FSD**	**80% IA**	**80% IA + FSD**
Number of Events	0	0	6080	0	6569	0	7044	0	7858	0	7972
Daily Mean Storage (ac-ft)	0	0.0	0.2	0.0	0.6	0.0	1.1	0.0	1.4	0.0	1.9
Daily Peak Storage (ac-ft)	0	0	12	0	23	0	35	0	47	0	59

System Outflow Histogram & Data

Σ Statistics - System Outflow

Summary | Events | Histogram | Frequency Plot

Rank	Start Date	Event Duration (hours)	Event Mean (CFS)	Exceedance Frequency (percent)	Return Period (years)
1	08/18/2004	89.0	17.018	0.03	66.00
2	08/02/1951	93.0	16.512	0.05	33.00
3	05/05/1973	105.0	15.584	0.08	22.00
4	09/10/2013	141.0	15.366	0.11	16.50
5	04/13/1967	100.0	14.653	0.13	13.20
6	04/26/1972	99.0	13.614	0.16	11.00
7	07/13/2013	85.0	13.415	0.18	9.43
8	06/10/1970	111.0	12.358	0.21	8.25
9	05/08/1957	120.0	12.008	0.24	7.33
10	08/16/2000	110.0	11.083	0.26	6.60
11	06/04/1965	95.0	10.852	0.29	6.00
12	07/09/1998	109.0	10.827	0.32	5.50
13	05/04/1969	157.0	10.550	0.34	5.08
14	05/18/1988	118.0	10.339	0.37	4.71
15	07/25/1991	82.0	9.749	0.39	4.40
16	07/30/1956	152.0	9.285	0.42	4.13
17	06/20/1967	87.0	8.521	0.45	3.88



WATER RIGHTS ANALYSIS

Objectives

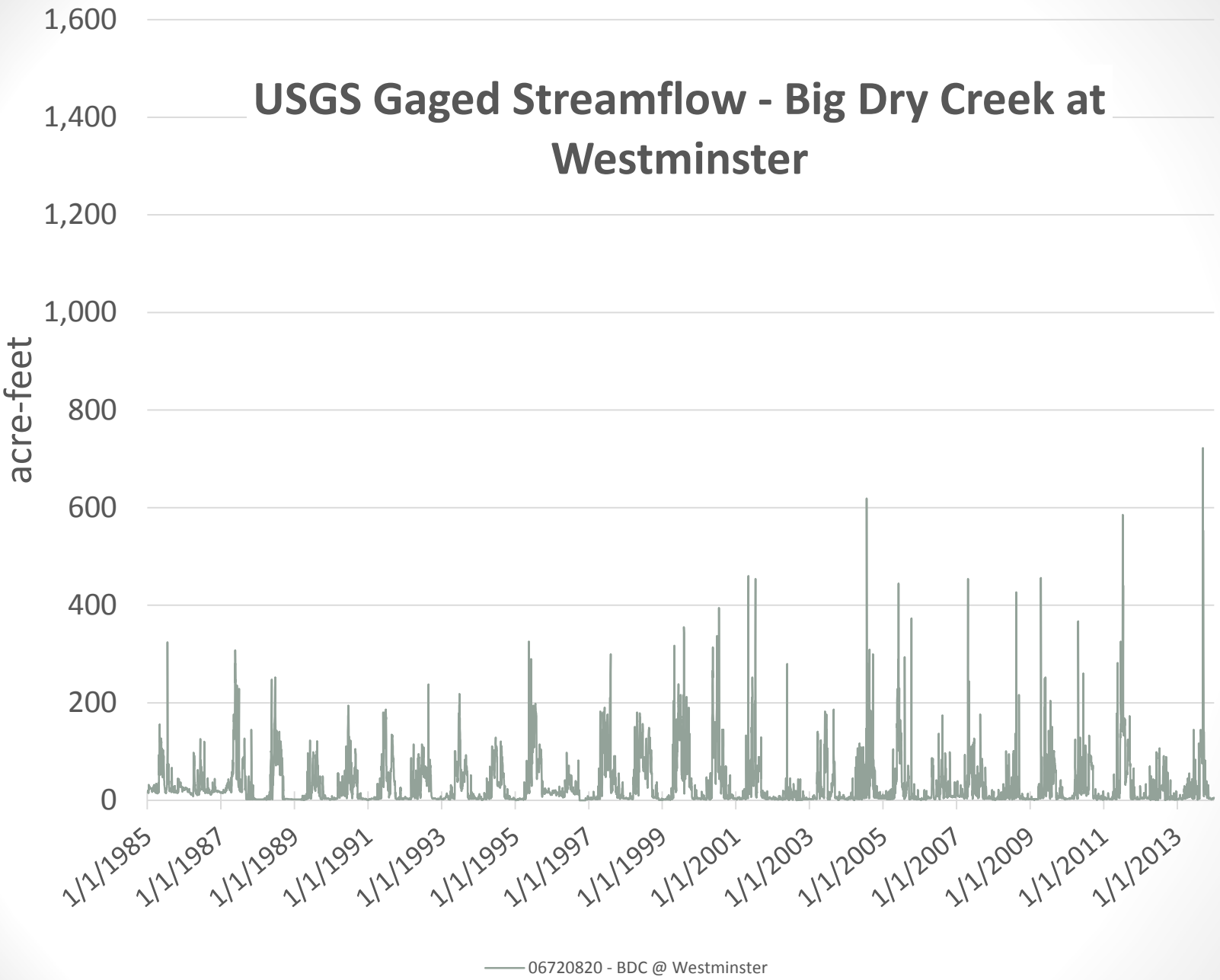
- There's more water, but is there really?
  - Colorado's water landscape depends on snowpack, runoff and return flows for a healthy watershed.
- Big Dry Creek flows support South Platte River diversions
- Historical river calls impact on Big Dry Creek
- Water rights holders and Big Dry Creek diversions
- Who benefits from FSD as a result of recent legislation?

Where is the Water on Big Dry Creek?

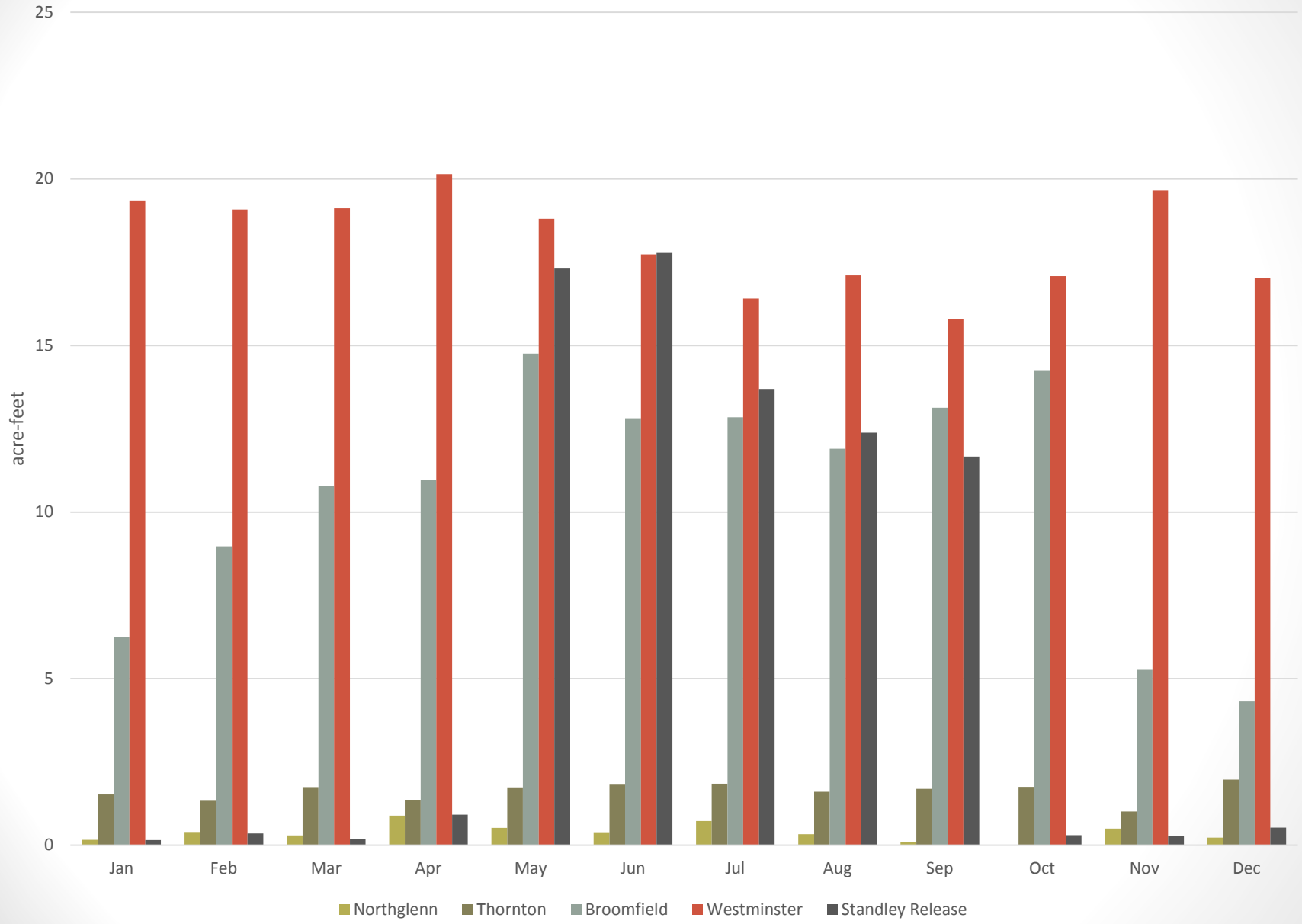
- USGS & DWR stream gages in Westminster and Ft. Lupton.
  - Gaining reach due to non-native flows.
- Transbasin diversions, reservoir releases and municipal waste water treatment effluent.
- No river calls on Big Dry Creek.
- Big Dry Creek serves as a conduit for augmentation deliveries and releases made to the South Platte.
- Big Dry Creek diversion structures divert both native and non-native flows.

Where is the Water on Big Dry Creek?

- Colorado's Decision Support System
  - State supported and publicly available data for Colorado's climate, streamflow and diversion records
  - Water rights related transactions and net decreed amounts relative to the Big Dry Creek system
- Colorado's Division of Water Resources
  - Call chronology of Colorado's river basins
  - South Platte River Basin's Division 1 office for municipalities accounting submittals
- Outflow from full spectrum detention and runoff as a result of development in the Big Dry Creek basin
- Evapotranspiration from rainfall events
- Lagged groundwater returns to Big Dry Creek and the South Platte River


USGS Gaged Streamflow - Big Dry Creek at Westminster
acre-feet
1,600
1,400
1,200
1,000
800
600
400
200
0
1/1/1985
1/1/1987
1/1/1989
1/1/1991
1/1/1993
1/1/1995
1/1/1997
1/1/1999
1/1/2001
1/1/2003
1/1/2005
1/1/2007
1/1/2009
1/1/2011
1/1/2013
06720820 - BDC @ Westminster

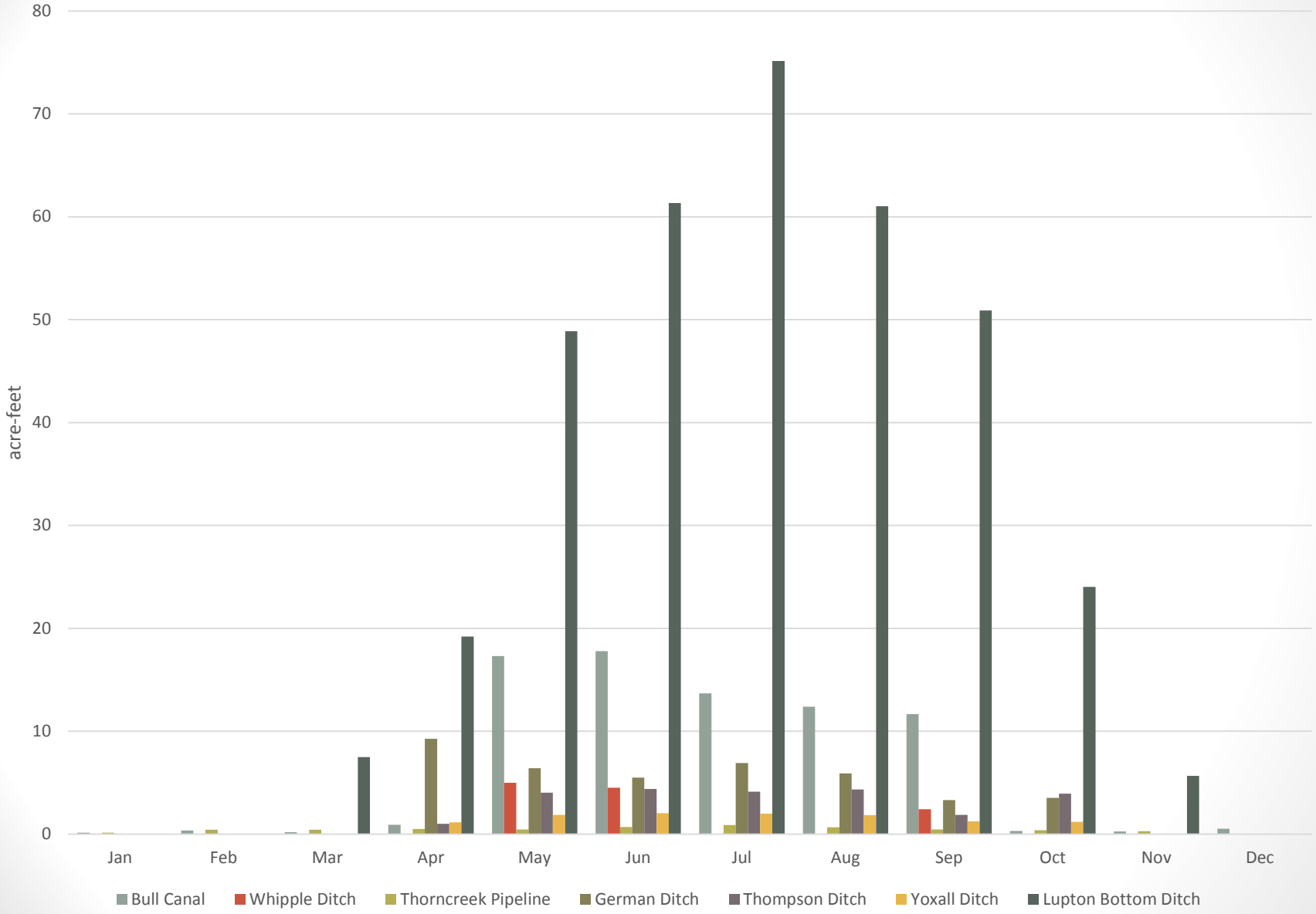
Average Monthly Inflows on Big Dry Creek

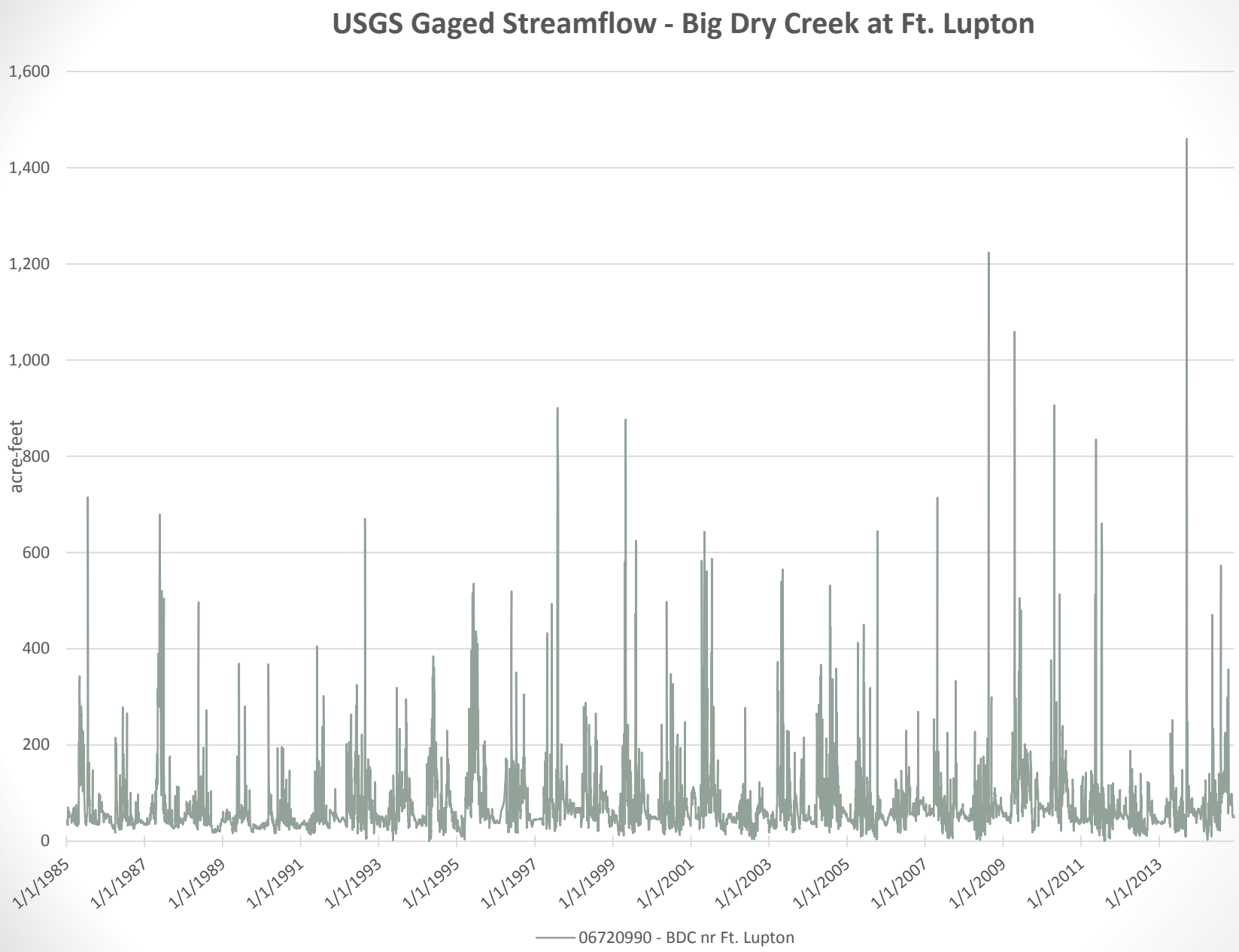


Water Rights on Big Dry Creek

						Decreed Amount (cfs)		
Structure ID	Water Right Name	Appropriation Date	Administration No.	Case No	Decreed Use	Absolute	Conditional	Alternate Point
872	German Ditch	1885-11-30	13118.00000	CA8568	Irrigation	0.99		
871	Bull Canal (Whipple Ditch)	1885-12-31	13149.00000	CA8568	Irrigation	0.99		
871	Bull Canal (Whipple Ditch)	1884-09-01	15895.12663	CA54658	Irrigation	5		
872	German Ditch	1885-11-25	15895.13113	01CW0273	Irrigation	40		
873	Big Dry Creek Ditch	1889-12-15	15895.14594	CA54658	Irrigation	36.66		
874	Yoxall Ditch	1896-07-27	17010.00000	CA40750	Irrigation	16.8		
880	Thornton Golf Course Pipeline	1987-12-10	50382.00000	96CW0244	Irrigation, Recreation, Other Beneficial Uses	5		140
880	Thornton Golf Course Pipeline	1996-12-31	53691.00000	96CW1116	Municipal			130
871	Bull Canal (Whipple Ditch)	2004-11-15	56567.00000	04CW0310	Municipal		31	
871	Bull Canal (Whipple Ditch)	2004-12-20	56602.00000	04CW0310	Municipal			21

Average Monthly Big Dry Creek Diversions




USGS Gaged Streamflow - Big Dry Creek at Ft. Lupton
1,600
1,400
1,200
1,000
800
600
400
200
0
acre-feet
1/1/1985
1/1/1987
1/1/1989
1/1/1991
1/1/1993
1/1/1995
1/1/1997
1/1/1999
1/1/2001
1/1/2003
1/1/2005
1/1/2007
1/1/2009
1/1/2011
1/1/2013
06720990 - BDC nr Ft. Lupton

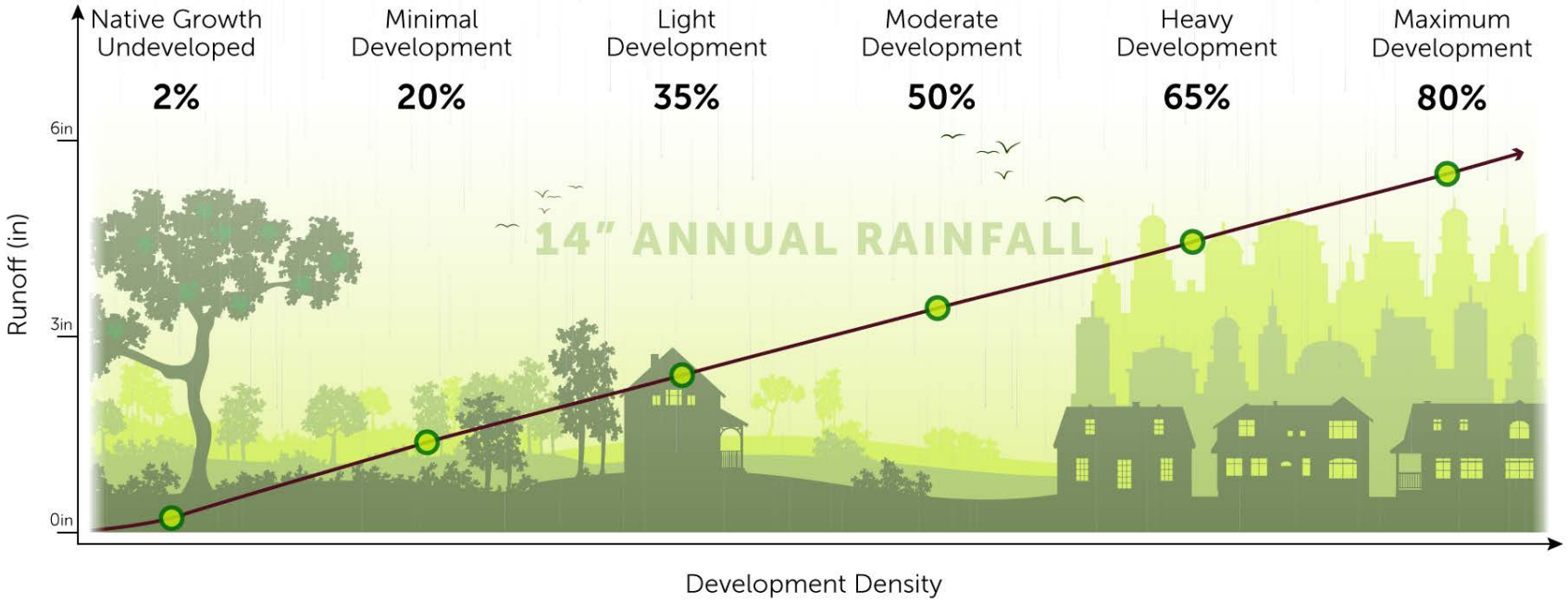
Return Flow and ET

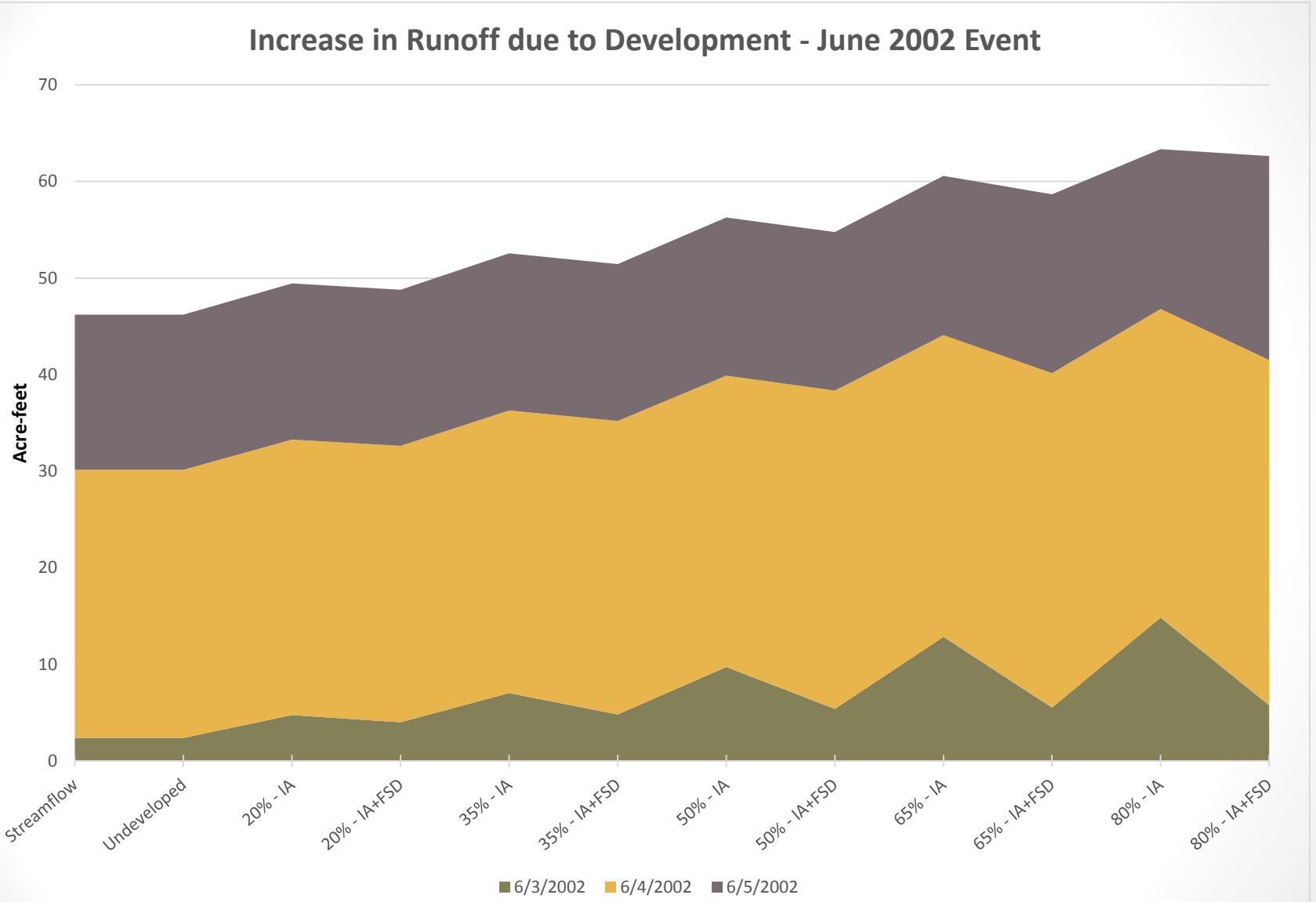
- Colorado water rights holders depend on subsurface flows as a result of rainfall, reservoir seepage and irrigation use.
  - Farm irrigation is large contributor to groundwater return flows.
  - Undeveloped scenario losses are a result of evapotranspiration.
- Development removes the lagged component of native ET from the system.
  - Long-term ET is re-timed through FSD and available to water rights holders in greater and more immediate quantities.
  - The lagged component returning to the stream is de minimis relative to an undeveloped area.

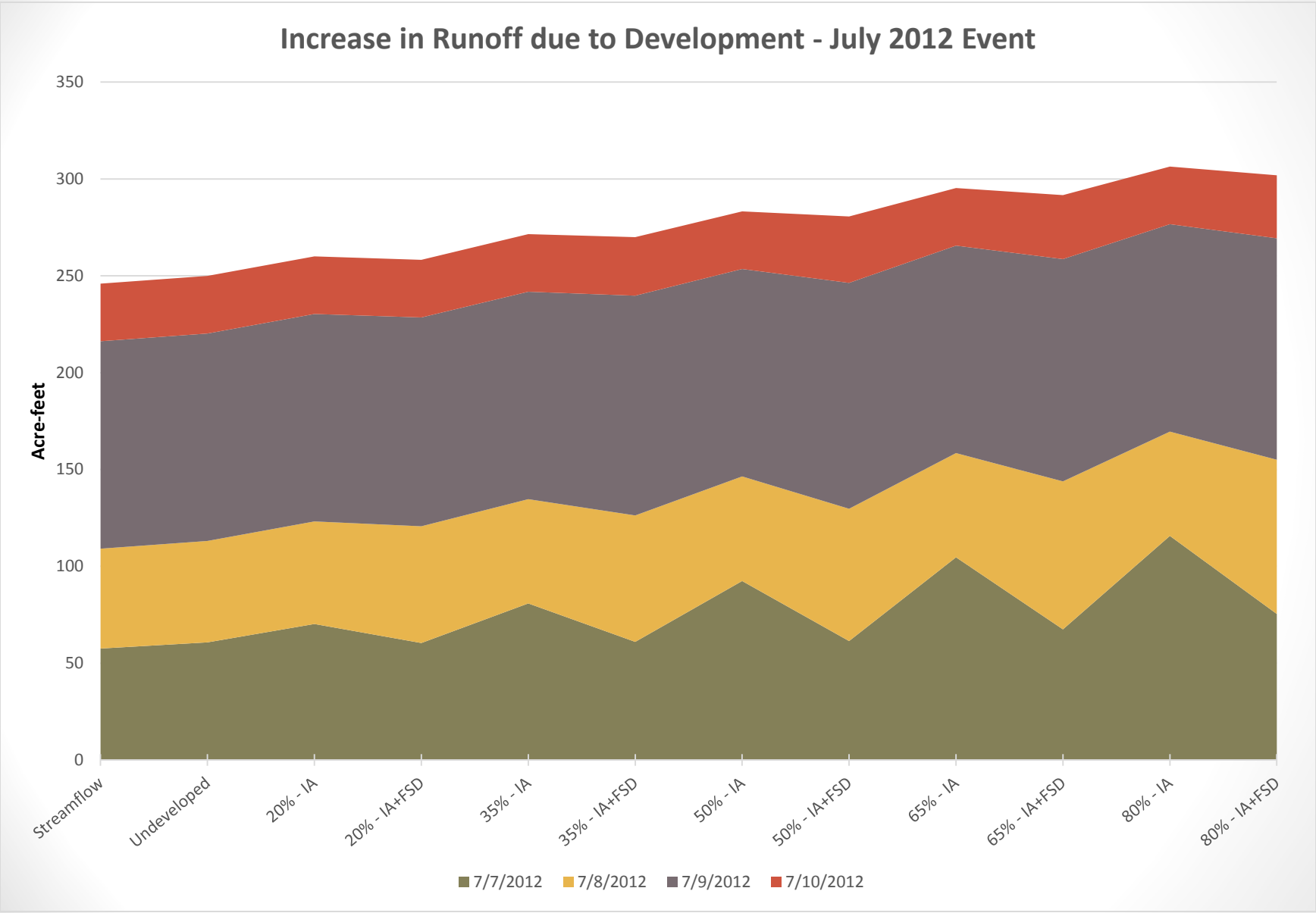
Effects of FSD

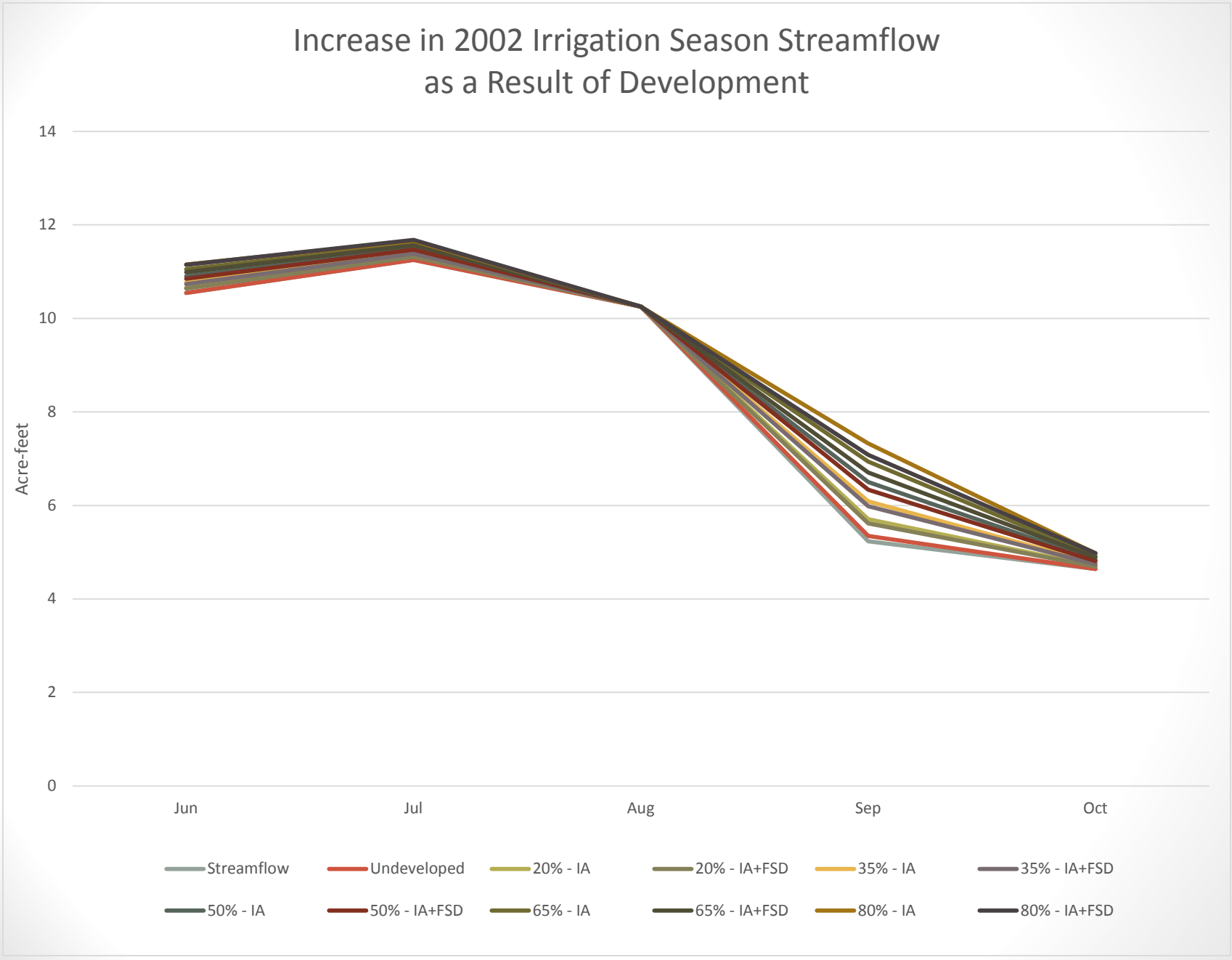
- Colorado water rights holders
  - Municipalities
  - Augmentation Plans
- Peak flow from rainfall events increase physical flow in subsequent days
- Big Dry Creek and South Platte River water rights may divert more water

Runoff due to Various Densities of Development




Increase in Runoff due to Development - June 2002 Event
70
60
50
40
30
20
10
0
Acre-feet
Streamflow
Undeveloped
20% - IA
20% - IA+FSD
35% - IA
35% - IA+FSD
50% - IA
50% - IA+FSD
65% - IA
65% - IA+FSD
80% - IA
80% - IA+FSD
6/3/2002
6/4/2002
6/5/2002


Increase in Runoff due to Development - July 2012 Event
Acre-feet
350
300
250
200
150
100
50
0
Streamflow
Undeveloped
20% - IA
20% - IA+FSD
35% - IA
35% - IA+FSD
50% - IA
50% - IA+FSD
65% - IA
65% - IA+FSD
80% - IA
80% - IA+FSD
7/7/2012
7/8/2012
7/9/2012
7/10/2012


Increase in 2002 Irrigation Season Streamflow
as a Result of Development
Acre-feet
14
12
10
8
6
4
2
0
Jun
Jul
Aug
Sep
Oct
Streamflow
Undeveloped
20% - IA
20% - IA+FSD
35% - IA
35% - IA+FSD
50% - IA
50% - IA+FSD
65% - IA
65% - IA+FSD
80% - IA
80% - IA+FSD

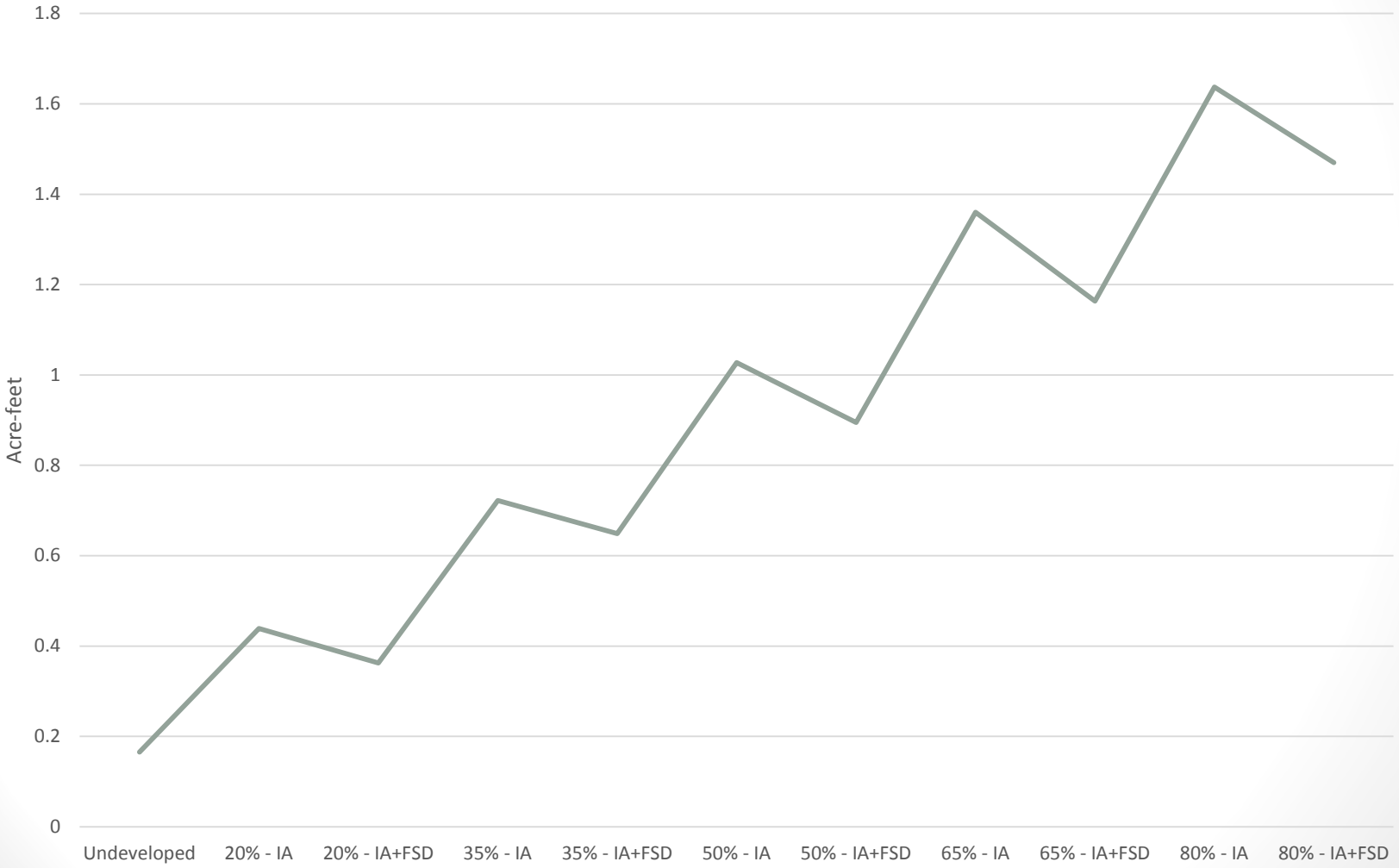
Runoff during South Platte River Calls as a Result of Development

Units in acre-feet

	Admin #	Call Structure	Days	Percent	Undeveloped	20% - IA	20% - IA+FSD	35% - IA	35% - IA+FSD	50% - IA	50% - IA+FSD	65% - IA	65% - IA+FSD	80% - IA	80% - IA+FSD
	No Call		13,883	60%	728	2,553	2,380	4,512	4,583	6,762	7,003	9,328	9,622	11,297	12,498
German Ditch - 1st Priority; Bull Canal - 1st Priority	5803.00000	FARMERS INDEPENDENT DITCH	50	0.22%	0	3	1	5	2	8	3	11	4	13	6
	5965.00000	MEADOW ISLAND 1 DITCH	190	0.82%	18	46	39	76	67	107	89	142	124	170	161
	5967.00000	MEADOW ISLAND DITCH	143	0.61%	24	63	52	103	93	147	128	195	166	234	210
	5969.00000	HEWES COOK DITCH	146	0.63%	0	12	9	24	17	39	26	56	34	67	44
	7671.00000	PLATTEVILLE DITCH	10	0.04%	0	0	0	0	0	0	0	0	0	0	0
	7739.00000	LUPTON BOTTOM DITCH	1	0.00%	0	0	0	0	0	0	0	0	0	0	0
	7892.00000	HEWES COOK DITCH	126	0.54%	5	23	13	43	19	62	24	83	43	100	67
	7948.00000	EVANS NO 2 DITCH	1,476	6.35%	145	343	265	552	446	782	594	1,039	796	1,236	1,038
	7975.00000	BRIGHTON DITCH	375	1.61%	0	37	28	73	54	117	86	167	127	205	175
	8127.00000	FARMERS HIGHLINE CNL	53	0.23%	0	12	10	25	21	41	32	60	45	75	59
	8218.00000	BRANTNER DITCH	32	0.14%	0	2	2	4	3	6	7	8	10	10	11
	8659.00000	LUPTON BOTTOM DITCH	136	0.58%	65	111	87	161	128	213	151	270	191	317	237
	8689.00000	PLATTEVILLE DITCH	109	0.47%	55	87	66	121	94	157	111	195	144	226	181
	9075.00000	UNION DITCH	196	0.84%	12	48	35	88	65	128	93	173	136	209	186
	9597.00000	MEADOW ISLAND DITCH	3	0.01%	0	0	0	0	0	0	0	0	0	1	1
	9686.00000	FULTON DITCH	501	2.15%	12	98	68	189	120	292	177	406	271	497	386
	9821.00000	FARMERS INDEPENDENT DITCH	271	1.17%	0	34	28	67	61	107	100	154	132	189	171
	10180.00000	LOWER LATHAM DITCH	243	1.05%	48	141	92	238	157	345	212	460	289	558	371
	10184.00000	CHURCH DITCH	1	0%	0	0	0	0	0	0	0	0	0	0	0
	10215.00000	MEADOW ISLAND DITCH	26	0.11%	0	2	2	4	3	6	5	9	7	10	9
	10480.00000	DENVER CONDUIT NO 20	2	0.01%	0	0	0	0	0	0	0	0	0	0	0
	10546.00000	CHURCH DITCH	1	0%	0	0	0	0	0	0	0	0	0	0	0
	10610.00000	HIGHLINE CNL	93	0.40%	87	133	122	187	183	237	213	290	281	332	328
	10901.00000	FULTON DITCH	15	0.06%	0	7	2	15	3	24	5	34	9	43	17
	11139.00000	DENVER CONDUIT NO 20	5	0.02%	0	1	0	1	1	2	1	2	2	3	2
	11338.00000	BRANTNER DITCH	68	0.29%	0	3	3	6	7	10	14	15	19	17	23
	11620.00000	LOWER LATHAM DITCH	156	0.67%	2	32	27	63	57	99	92	140	131	173	171
	11629.00000	UNION DITCH	2	0.01%	0	0	0	0	0	0	0	0	0	0	0
	11807.00000	MEADOW ISLAND 1 DITCH	15	0.06%	0	0	0	0	0	0	0	0	0	0	0
	13108.00000	BURLINGTON D RIVER HEADGATE	2,164	9.31%	63	409	360	769	698	1,187	1,063	1,665	1,435	2,031	1,899
Bull Canal Pr2	14423.00000	CHEESMAN RES	106	0.46%	0	13	9	25	17	41	26	59	37	72	53
	14519.00000	DENVER CONDUIT NO 20	0	0.00%	0	0	0	0	0	0	0	0	0	0	0
	15585.00000	DENVER CONDUIT NO 20	6	0.03%	0	0	0	0	0	0	0	0	0	0	0
BDC Ditch	15973.00000	CHEESMAN RES	23	0.10%	75	90	75	108	106	123	121	138	137	151	156
Thorncreek Pipeline; Bull Canal	18018.00000	DENVER CONDUIT NO 20	26	0.11%	0	0	0	0	0	0	0	0	0	0	0
	19055.00000	CROKE CANAL	18	0.08%	0	0	0	0	0	0	1	0	2	0	3
	21150.00000	BURLINGTON D RIVER HEADGATE	21	0.09%	0	1	1	2	1	2	2	3	3	4	4
	21252.00000	BURLINGTON D RIVER HEADGATE	102	0.44%	0	13	11	25	21	41	33	59	46	71	59
	21562.00000	BURLINGTON D RIVER HEADGATE	1,313	5.65%	4	141	132	283	280	453	465	649	673	798	891
	21698.00000	MILTON RES	139	0.60%	0	6	6	12	12	20	20	29	32	35	46
	21709.00000	EVANS NO 2 DITCH	9	0.04%	0	0	0	1	1	1	1	1	1	1	2
	22239.00000	BURLINGTON D RIVER HEADGATE	115	0.49%	0	2	2	4	4	7	6	9	9	11	11
	22254.00000	DENVER CONDUIT NO 20	20	0.09%	0	0	0	0	0	0	0	0	0	0	0
	22355.00000	HORSE CREEK RES	48	0.21%	0	6	6	11	17	18	27	26	37	31	48
	22370.00000	MARSTON RES FROM (SEE 0903501)	15	0.06%	0	4	2	8	5	13	9	19	15	23	23
	25050.21709	EVANS NO 2 DITCH	33	0.14%	0	6	7	13	18	21	30	30	31	38	39
	46748.00000	CHATFIELD RESERVOIR	137	0.59%	5	32	27	61	59	92	92	126	117	153	143
	47481.40987	DENVER CONDUIT NO 20	7	0.03%	0	0	0	0	0	0	0	0	0	0	0
	48974.00000	BURLINGTON D RIVER HEADGATE	12	0.05%	0	2	2	4	3	6	6	9	7	11	9

Average Daily Increase in Runoff during South Platte River Call

Meadow Island Ditch



CONCLUSIONS

Conclusions

- Development increases impervious area which decreases evaporation/ET and increases runoff
- Surface water yield from undeveloped to developed conditions changes dramatically, more so at higher impervious levels
- Evaporation/ET in model is not sensitive to effects of FSD
  - Depression storage following rainfall
  - Soil moisture availability for ET (upper aquifer zone)
- FSD attenuates peak discharges and extends release hydrographs

Conclusions

- SWMM Model trends follow expected patterns with increasing imperviousness
- FSD primarily affects the timing of runoff (relative to same scenario) without FSD, quantity effects are minor
- Increased flow along the Front Range is coveted and will help water rights holders reduce the supply/demand gap
- Following rainfall events in dry years, water rights holders will benefit from increased flow in subsequent days as a result of FSD

Questions & Comments?