

Hydrologic Analysis

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Introduction

This report is part of Phase 1, Technical Assessment, for the purpose of establishing a factual baseline of watershed conditions for the Illinois River. The amount and condition of vegetation is a primary input to evaluating watershed hydrologic conditions. The management of the land and vegetation throughout the watershed affects runoff and downstream flows. The flood flows change the channel shape and the channel sinuosity, impacting fishery and aquatic habitat. Changes in channel elevation and movement of gravel affect water storage in the riparian zone, impacting low flows critical to stream temperature and available water in the summer. The peak flows from storm hydrographs, and the resulting velocities, are to be used to evaluate such changes, as part of resource planning.

Summary of Concerns

The resource planning is to address the impact of storm flows increasing velocity, and resulting channel changes raising concerns including:

1. Streambed materials with size beneficial to fishery habitat are reduced.
Increased storm flow velocities, resulting from decreased quality of hydrologic cover condition, results in excessive transport capacity removing sands and gravel from sub-watershed streams. Sands and gravels are stream bed materials with size beneficial to fishery and other aquatic habitat.
2. Flow and flow duration during late summer and early fall are reduced.
Increased scour of stream bed sands and gravels (associated with increased storm flow velocities) and soil erosion delivering fine sediments to streams is caused by degraded hydrologic condition. Lost with the sand and gravel reservoirs is water storage in stream beds. These reservoirs provide flow of cool water to pools and downstream channels during late summer and early fall. Fine sediment fills pore spaces decreasing flow of water and oxygen into and through the streambed. Loss of this flow is detrimental to fishery habitat.
3. Low flow water temperature is increased.
Increased storm flow velocities can alter channel shape and riparian vegetation. The altered streams are typically wider and shallower because of the increased stream energy provided by the increased flow volume and velocity. Solar energy acting on a wider and shallower stream increases water temperature.

Scope and Objectives

Three watershed conditions are considered. The conditions include vegetative cover of 1996 as “Present”, vegetative cover reference conditions of “Full Cover” and the mid-1960’s cover considered to be “Historic”. The conditions are defined using products including Watershed Vegetation Analysis developed by others as part of the watershed assessment. The digitized map data of Appendix A is used to establish watershed runoff conditions. The resulting watershed conditions are used to develop the rainstorm hydrographs of this report.

The storm hydrographs are useful in evaluation of alternatives for riparian management. The results should provide insight to management and land use.

Results and Discussion

The peak flows from the storm hydrographs are shown in **Table 4**. The flows are for watershed vegetative conditions of Full Cover, Present Cover (1996), and Historic Cover (mid-1960’s). The peak flows are tabulated for rainstorms, including the 2, 5, 10, 25, 50, and 100-year average return periods. The larger storms include discharges over the channel bank and floodplain. Base flow and snowmelt runoff are included. The contribution of base flow and snowmelt runoff is small relative to runoff from storm precipitation.

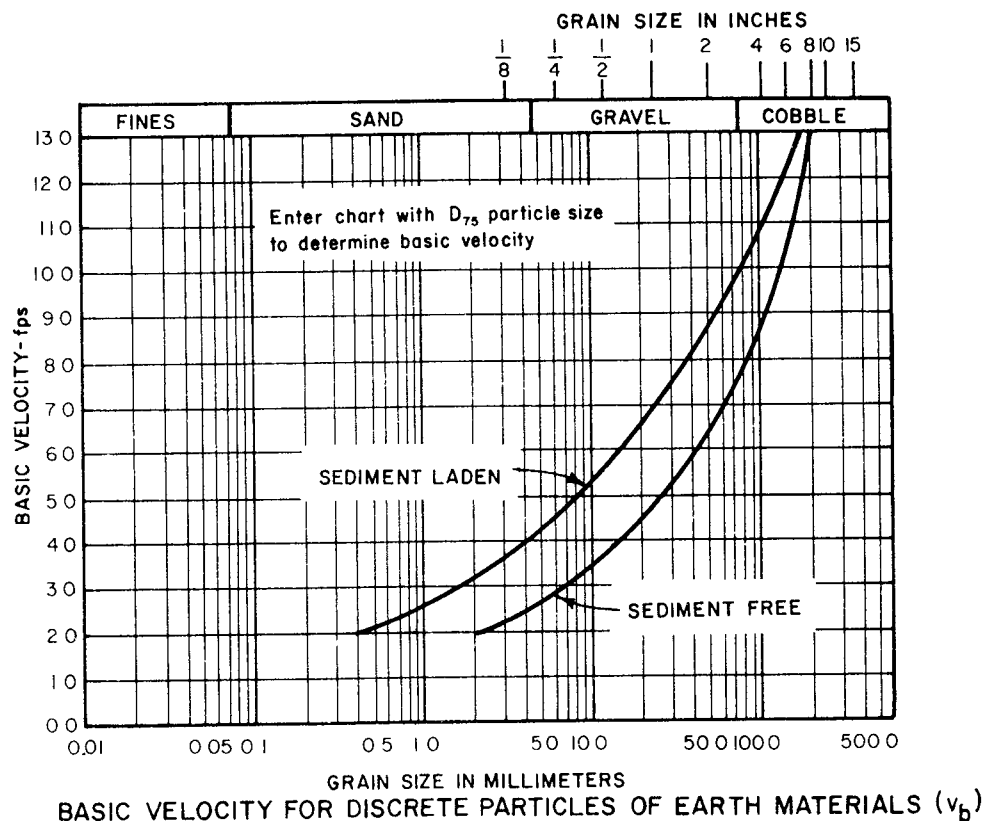
Peak flows under full cover are smaller than peak flows under present or historic conditions. Josephine Creek has little change as seen in the 5-year flow being an increase of 1 percent in the 1960’s, and 6 percent increase for present condition relative to the full cover condition. The East Fork Illinois River shows more change with a 22 percent increase in the 1960’s, and a 34 percent increase for present condition, relative to the full cover condition and 5-year storm. At the gauge near Agnes for the years 1961-1981, the 25-year peak flow is 170,000 cubic feet per second (cfs). That compares to the 169,990 cfs computed by TR-20¹ procedures. The peak flow for the 10-year storm is 138,000 cfs at the gauge, whereas the TR-20 procedure value is 122,000 cfs for the present condition. The results are reasonable for this level of analysis (Cleary et al,1999). Additional flow information for subwatersheds, including Indigo Creek, Silver Creek and Lawson Creek, is provided with analysis materials at the NRCS office in Grants Pass.

Increases in peak flows for a rainstorm event result from increased direct runoff from the decreased vegetative cover condition, from full cover, to historic, to present. The degraded condition reduces storage of rainwater on vegetation and plant litter, and decreases infiltration. The direct runoff increases are computed by equations transforming the stored precipitation to the hydrologic condition indexed by a runoff curve number. (Additional description of the curve numbers evaluated for the sub-watersheds is provided in discussion of Table 8.)

¹ NRCS Technical Release 20, Computer Program for Project Formulation Hydrology (TR-20). TR-20 is a physically based event model used to develop flood hydrographs from runoff .

Peak flow velocities in Table 5 were computed using estimates of channel bottom width and bank slope from available records. The velocities are representative of average within bank flow velocity and are considered suitable for the level of this analysis. Additional stream channel cross-sections and water surface profile analyses would be necessary to refine the estimates.

The mountain terrain and the shallow soils result in a relatively short time lag following precipitation and the rapid rise in streamflow. The delivery of sands and gravels to streams and transport in streams occurs during the higher velocity period of the storm flow. Stream materials are transported for the sizes of materials occurring in the stream bed when the flow velocity is sufficient. Figure 1 below illustrates the basic velocity (V_b) required. Additional factors which modify this velocity are flow depth, stream curve alignment and the bed's bank slope. The storm flows in the Illinois River stream increase rapidly; additional increases in flow velocity are not considered beneficial to the salmon fishery (David Haight, ODFW, personal communication).



Erosion in the watershed increases with the degraded vegetative cover condition. Sediment delivered to the stream system is increased. Sediment transport in the streams is increased with the greater rate of runoff. During periods of higher flow velocities, additional gravels are stripped from the stream bed. Fine sediments are deposited during the later, reduced storm flow. Fine sediments remaining in suspension increase heat gain from solar radiation. Loss of the gravels reduces the natural storage of the stream system. The gravels provide a reservoir of cool water for release to salmon and other aquatic habitat during critical periods of late summer and early fall. The fine sediments return to the stream bed. They fill voids in the gravel reducing water storage, reducing porosity, and restricting subsurface return flow of cooler temperature water at critical periods (Paul Pedone, NRCS, personal communication).

TABLE 4, ILLINOIS RIVER WATERSHED PEAK FLOWS (CUBIC FEET PER SECOND)

Name and Location	Area sq mi	Watershed Condition	Rainstorm Average Return Period					
			2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
East Fork Illinois River	89.60	Present (1996)	7400	10700	13600	19000	23300	27800
		Full Cover	5400	8000	10500	15400	19400	23500
		Historic (1960's)	6700	9800	12600	17800	22000	26400
Althouse Creek, outlet	45.90	Present (1996)	3600	4800	6200	8200	10000	12200
		Full Cover	2600	3500	4700	6600	8200	10200
		Historic (1960's)	3400	4600	5900	7900	9700	11800
East Fork Illinois River (below Althouse Creek)	135.50	Present (1996)	10900	15300	19400	26700	32700	39200
		Full Cover	8000	11500	15100	21700	27200	33200
		Historic (1960's)	10000	14200	18100	25300	31200	37500
Sucker Creek, outlet	96.40	Present (1996)	4000	5400	8100	12400	16600	19900
		Full Cover	3600	4900	7400	11500	15500	18600
		Historic (1960's)	3900	5300	8000	12200	16400	19600
East Fork Illinois River (below Sucker Creek)	231.90	Present (1996)	13800	19500	26200	37700	47700	57100
		Full Cover	11100	15500	21600	32000	41400	50300
		Historic (1960's)	12900	18300	24900	36100	46000	55300
Illinois River, near Kerby gauge	351.10	Present (1996)	29100	40500	52500	71000	87800	101900
		Full Cover	23800	33780	44900	62300	78100	91500
		Historic (1960's)	27400	38340	50100	68300	84800	98700
Josephine Creek, outlet	43.08	Present (1996)	9100	12400	15000	18700	22200	25400
		Full Cover	8500	11700	14300	17900	21400	24600
		Historic (1960's)	8500	11800	14300	18000	21400	24700
Illinois River, below Deer Creek	506.71	Present (1996)	38800	54200	70200	94800	117100	135900
		Full Cover	32300	45700	60500	83400	104600	122500
		Historic (1960's)	36700	51600	67200	91400	113400	131900
Illinois River, below Collier Creek	610.07	Present (1996)	44900	61800	80600	109000	135400	158300
		Full Cover	38700	53500	71000	97800	122800	144600
		Historic (1960's)	42800	59100	77500	105500	131400	154100
Illinois River, outlet (near Agness)	982.18	Present (1996)	74200	99000	127400	170000	210600	245700
		Full Cover	66300	88400	115100	155300	194100	227600
		Historic (1960's)	70600	94300	122100	163900	203900	238300

A two-year return period means that such a storm is expected to occur every two years on the long term. A 100-year return period means that the storm is expected to occur, on the average, once in a 100-year period. Either storm could occur more than once in a period of a few years. In a given year, the 2-year storm has a 50 percent chance, and the 100-year storm has a 1 percent chance of occurring.

In a natural setting, the channel width and depth correlate with the velocities and peak flows of about the 1.5 year recurrence interval. The detachment and transport capacity of the stream increases with the stream velocity. **Table 5** shows velocities associated with the TR-20 calculated peak flows. Josephine Creek, with little change in watershed condition, has little change for the 5-year storm with the velocity being 10.2 feet/second for both the full cover and 1960's condition, and 10.4 feet/second for the present condition. The East Fork Illinois River velocity increase is about 8 percent for the 1960's (12.6 to 13.6) and 12 percent (12.6 to 14.1) for present conditions above the full cover condition.

**TABLE 5, ILLINOIS RIVER SUBWATERSHEDS
PEAK FLOW VELOCITY, FEET/SECOND**

Name and Location	sq mi	Watershed Condition	Average Return Period		
			2 yr	5 yr	10 yr
East Fork Illinois River	89.60	Present (1996)	12.3	14.1	15.3
		Full Cover	10.9	12.6	13.4
		Historic (1960's)	11.9	13.6	14.3
Althouse Creek, outlet	45.90	Present (1996)	9.8	10.7	11.7
		Full Cover	8.8	9.7	10.2
		Historic (1960's)	9.6	10.6	11.1
East Fork Illinois River (below Althouse Creek)	135.50	Present (1996)	9.7	10.9	11.8
		Full Cover	8.7	9.9	10.4
		Historic (1960's)	9.4	10.6	11.1
Sucker Creek, outlet	96.40	Present (1996)	9.1	10.2	12.0
		Full Cover	8.8	9.9	11.1
		Historic (1960's)	9.1	10.2	11.4
East Fork Illinois River (below Sucker Creek)	231.90	Present (1996)	10.0	11.2	12.4
		Full Cover	9.3	10.4	11.2
		Historic (1960's)	9.8	11.0	11.7
Illinois River, near Kerby gauge	351.10	Present (1996)	12.2	13.6	14.2
		Full Cover	11.4	12.8	13.5
		Historic (1960's)	11.9	13.3	14.0
Josephine Creek, outlet	43.08	Present (1996)	9.3	10.4	11.2
		Full Cover	9.1	10.2	10.6
		Historic (1960's)	9.1	10.2	10.6
Illinois River, below Deer Creek	506.71	Present (1996)	13.3	14.9	15.6
		Full Cover	12.5	14.1	14.9
		Historic (1960's)	13.1	14.7	15.4
Illinois River, below Collier Creek	610.07	Present (1996)	16.8	18.7	19.6
		Full Cover	16.0	17.8	18.8
		Historic (1960's)	16.5	18.4	19.4
Illinois River, outlet (near Agness)	982.18	Present (1996)	12.4	13.6	14.2
		Full Cover	11.9	13.1	13.8
		Historic (1960's)	12.2	13.4	14.0

Other methods of estimating peak flows include the procedure from USGS Report 94-4002, and the procedure of the Oregon State Engineer (OSE), 1971 Watershed Planning Division. Peak flows using these procedures are shown in **Table 6** as a ratio to the peaks determined with TR-20 procedures for the selected subwatersheds and storms.

Generally, the TR-20 procedure yields smaller peak flows. An exception is Josephine Creek where precipitation and runoff curve number values are substantially higher than for the other subwatersheds in the table.

The procedures based only on stream gauge data do not generally allow consideration of variation in subwatershed topography, soils or changes in management or vegetation. The TR-20 procedures consider changes in runoff due to changes in vegetative cover and land management. The TR-20 procedure allows inputs of topography and soils for evaluation of subwatershed variation and the changed conditions. For this study, TR-20 is the method of choice.

**TABLE 6, PEAK FLOW RATIOS FOR SELECTED PROCEDURES, STORMS,
AND
ILLINOIS RIVER SUBWATERSHEDS, PRESENT WATERSHED CONDITION**

Subwatershed	Area sq mi	5 yr average return period			100 yr average return period		
		USGS	TR20	OSE	USGS	TR20	OSE
Althouse Creek	45.9	1.29	1	1.16	1.65	1	1.10
Sucker Creek	96.4	2.18	1	1.85	1.87	1	1.23
East Fork Illinois River	89.6	1.27	1	0.89	1.58	1	0.83
Josephine Creek	43.1	0.68	1	0.42	1.06	1	0.50

A precipitation depth is determined for each subwatershed by visually weighting the area of the mapped values from National Oceanic and Atmospheric Administration (NOAA) Atlas 2 to the subbasin maps. The weighted values are plotted and smoothed in accord with the procedures of NOAA Atlas 2. Precipitation values are read from the smoothed plot line for the selected return periods. The recurrence interval for the storms is the recurrence interval of the precipitation, which is assumed to approximate the runoff recurrence interval. The amount of precipitation varies significantly with location and elevation as shown in **Table 7**. For example, the 5-year storm precipitation values range from 4.19 inches to 6.98 inches.

**TABLE 7, ILLINOIS RIVER SUBWATERSHEDS
RAINSTORM PRECIPITATION (INCHES)**

Subwatershed	Precipitation Average Return Period					
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
East Fork Illinois River	4.67	5.60	6.07	7.01	7.66	8.41
Althouse Creek	4.18	4.75	5.23	5.89	6.46	7.13
Sucker Creek	3.92	4.67	5.13	5.78	6.34	6.81
West Fork Illinois River	5.15	6.18	6.93	7.96	8.89	9.73
Rough & Ready Creek	5.74	6.98	7.84	8.89	9.75	10.80
Josephine Creek	5.33	6.47	7.13	8.08	8.94	9.80
Deer Creek	3.44	4.19	4.65	5.30	5.86	6.32
Briggs Creek	4.71	5.55	6.21	7.06	7.72	8.47
Collier Creek	5.74	6.88	7.65	8.60	9.56	10.42
Illinois River, main stem	5.34	6.26	6.72	7.54	8.28	8.92
Silver Creek	5.43	6.47	7.31	8.25	9.09	9.93
Indigo Creek	5.44	6.66	7.41	8.35	9.29	10.13
Lawson Creek	5.43	6.67	7.43	8.39	9.34	10.29

The subwatersheds are sized to conform to resources available for development of GIS methods, and in accord with interagency team recommendations for critical habitat reaches. Runoff is computed using methods contained in NRCS National Engineering Handbook, Hydrology, Chapter 10, Estimation of Direct Runoff from Storm Rainfall. Runoff curve numbers are estimated for the present condition, full cover condition, and for the historic condition of the subwatershed in the mid-1960's. The curve numbers index runoff. Smaller curve numbers result in smaller amounts of runoff. **Table 8** shows the values for each subwatershed.

**TABLE 8, ILLINOIS RIVER SUBWATERSHEDS,
RUNOFF CURVE NUMBERS**

Subwatershed	Full Cover	Historic Cover (1960's)	Present Cover (1996)
Althouse Creek	64.4	68.6	69.5
Briggs Creek	68.9	70.0	70.4
Collier Creek	61.4	61.7	64.1
Deer Creek	64.0	67.2	67.9
East Fork Illinois River	62.1	66.0	67.8
Indigo Creek	60.1	60.8	63.2
Josephine Creek	76.2	76.3	77.9
Lawson Creek	57.9	58.4	59.0
Illinois River, main stem	72.0	73.0	74.7
Rough & Ready Creek	77.7	77.8	77.9
Silver Creek	68.9	69.4	72.0
Sucker Creek	58.9	60.8	61.3
West Fork Illinois River	68.4	71.3	73.0

Analysis and References

The peak runoff is computed for the changed watershed conditions using NRCS Technical Release 20, Computer Program for Project Formulation Hydrology (TR-20). TR-20 is a physically based event model used to develop flood hydrographs from runoff. Flow is routed through the channel system and routed hydrographs are combined with flow from tributaries. Small changes in the volume of runoff and velocity of flow can significantly change the calculated peak flow.

For routing, flows are combined at the times determined using the calculated flow velocity. Factors for velocity calculations include a roughness coefficient, channel shape and depth, and channel slope.

In this study, channel widths and depths of much of the upstream Illinois River subwatersheds are determined using the video taped aerial flights of August 30, 1995. Representative reaches are selected and coded using flight recorded time. Widths are measured, and roughness and depths are estimated, using the video. River lengths and slopes are determined using current USGS topographic maps.

Limited on-site visits support estimates of surface roughness. The Manning's roughness coefficient values range from 0.030 to 0.075 with the larger values due to the increased effects of rocks and brush retarding shallower flows. Hydraulic radius values range from 1.0 to 5.2 with the larger values reflecting increased depth of flow as slope decreases and flows are combined going downstream. Manning's roughness coefficients and hydraulic radius values are plotted with the channel slopes. The coefficient and radius values are extended to the unflown remainder of the Illinois River watershed. The channel slope is

used to select the channel roughness and hydraulic radius values for each of the upper, middle, and lower watershed positions of each unflown subwatershed. Adjustments are made with additional information on channels in various reported studies made available by the cooperating agencies.

A base flow, and snowmelt flows are added to the TR-20 computed rainstorm values. The added base flow is 10 cubic feet per second per square mile of drainage. The set of snowmelt runoff values developed by the authors is shown in **Table 9**.

TABLE 9, ILLINOIS RIVER SNOWMELT ESTIMATES

Snowmelt, inches/day	Average return period, years	Equivalent snowmelt runoff, Cubic feet/second/square mile
2.0	100	54
1.6	50	43
1.0	25	27
0.4	10	11
0	<10	0

The runoff from snowmelt varies with the depth and water content of snow, the presence of frozen soil, and the heat available to melt the snowpack. At higher elevations, more precipitation falls as snow and remains as snow for longer periods. In general, the potential rate of snowmelt in a forest increases rapidly as spring advances, ranging from about 0.02 inches in early spring to 0.05 inches in late spring per degree day (Branson et al, 1981). The average degree days in April is 18.7 (Owenby and Ezell, 1992) at Sexton Summit at elevation 3,836 feet, near the Illinois River watershed.

Runoff from snowmelt and rainfall increases significantly when rain falls on a partially melted snowpack with an underlying frozen soil layer. Records of snowmelt from the watershed, frozen soil, or records of rains on snow, are not available. Such would be useful, but not critical, for this study phase and would require resources for analysis that are not currently available. Accordingly, runoff from snowmelt is estimated by the authors to occur on 2/3 of each watershed, converted to equivalent flow rates for the entire watershed, and added to the storm runoff to reasonably match flow records of the Illinois River at the Agnes gauge.

For a given rainstorm, increased cover on the watershed generally increases the duration of flow, and reduces the peak. Flow for longer periods and with lower peaks is a more natural condition, given the forested history of the watershed. The more natural condition is generally beneficial. Study of flow duration and seasonal flows is needed to evaluate the benefits. Improved values may be needed for snowmelt runoff in critical reaches as amount and timing of snowmelt could be significant in evaluating changes in available water and stream temperatures resulting from watershed changes.

The opportunities to significantly improve the peak flow estimates and velocities include more division of subwatersheds, and field surveys to gather additional channel data at specific sites. Smaller subwatersheds would allow more detail for study of tributaries. On-site surveys could improve accuracy of channel data and results at critical locations. A study of winter conditions along with stream gauge data could improve the estimation of joint values of snowmelt and rainfall.

References

- Branson, Farrel A., Gerald F. Gifford, Kenneth G. Renard, and Richard F. Hadley. 1981. *Ed. Elbert H. Reid. Rangeland Hydrology. Society for Range Management.*
- Cleary, P. H., Gene Hickman, and G. E. Formanek. 1999. Supporting Data, Hydrologic Analysis of the Illinois River Watershed Assessment/Plan. (In review 6/99.)
- Owenby, James R. and D.S. Ezell. 1992. Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1961-1990. US National Oceanic and Atmospheric Administration.
- US Geological Survey. 1990. Statistical Summaries of Streamflow Data in Oregon: Volume 1--Monthly and Annual Streamflow, and Flow-Duration Values.
- US Geological Survey. 1982. Streamflow Characteristics Related to Channel Geometry of Streams in Western United States.
- US National Oceanic and Atmospheric Administration. 1973. NOAA Atlas 2, Precipitation Frequency Analysis of the Western US, Volume 10, Oregon.
- US Soil Conservation Service (now Natural Resources Conservation Service). 1992. Technical Release 20, Computer Program for Project Formulation Hydrology.
- US Soil Conservation Service (now Natural Resources Conservation Service). 1972. National Engineering Handbook, Section 4, Hydrology.