APPENDIX B - HYDROLOGY AND HYDRAULICS

This appendix includes: a description of the hydrologic and hydraulic investigations conducted as part of this report; a spreadsheet showing the hydrologic data used for each reach; a spreadsheet showing the hydraulic characteristics of each surveyed cross-section; and graphic representations of all surveyed cross-sections including the stage of common flow events.

Hydrology

The downstream hydrology on the Carson River is complex; particularly in the fact that flood magnitude tends to decrease down the river. To our knowledge, no one has completed a definitive flood frequency analysis for a wide range of flood return intervals throughout the river. For the purposes of this report, we have estimated flood-frequency and magnitude, by project reach, using USGS gage and other data. It should be noted that the estimates provided here are only approximations of the river's hydrology. A complete hydrologic analysis is beyond the scope of this report. However, we have confidence that the flood-frequency distributions presented here are reasonable estimates.

We first obtained USGS partial peak flow flood frequency distributions for 12 active and inactive gage sites covering both forks and the Carson Mainstem. The period of record of the gages ranged widely from close to 85 years to a low of 11 years, ranging in time from 1890 to 1996. Due to the short period of record of some of the newer gages, flood magnitude and frequency, in the downstream direction, could not be confidently predicted with this information alone. For example, many of the newer gage sites did not cover significant flood events, such as those that occurred in 1955 and 1964, so there frequency of occurrences did not correspond with gages with longer periods of record. Further, gage distribution down the river was not uniform, leaving large gaps in information. For example, between Reach C-3 and C-9, no gage information was available.

For the East Fork, our base line information came from USGS gage 1030900 (EF Carson NR Gardnerville, NV), which had a period of record of 76 years. The flood frequency distribution for this gage was used to estimate hydrology for Reaches E-1 through E-3. For E-4 through E-6, we utilized data collected and analyzed by an engineering firm who performed extensive hydraulic modeling through this area (Lidstone and Andersen 1993). The West Fork flows were more complicated to estimate, since overflow from the East Fork becomes West Fork flows at discharges exceeding the 25-year event. To estimate West Fork flows at the confluence with the Carson River, overflow values from the East Fork were added to gaged flows at the Woodfords site.

C-1 through C-3 flows were taken to be equivalent with Gage 10311000 (Carson NR Carson City, NV), which has a 57 year period of record. C-4 flows were taken as those at Gage 10311400 (Carson AT Deer Run Road NR Carson, NV). Despite the 11-year period of record, estimated flows appeared to match the trend for decreasing flows in the downstream direction. For C-5 through C-8, flows were back-calculated from Gage 10312000 (Carson NR Fort Churchill, NV), sited in C-9. This gage has a period of record covering 85 years, and was considered to be a reliable baseline. Flows were back-calculated by proportionally reducing the flows between C-4 and C-9 based on river miles between each site. Based on the fact that flows decrease downstream, we felt that proportioning by river mile was more accurate than watershed area (which is the usual method to apportion unknown flows between gaged sites).

Hydraulics

For each cross-section surveyed, hydraulic analysis was conducted using XSPRO software. XSPRO, developed by the U.S. Forest Service, is commonly used by hydrologists and engineers to relate cross-section data to flow characteristics. In the context of this report, the primary use was to develop stage-to-discharge and velocity relationships for a variety of flows ranging from the 1.25-year to the 100-year discharge. This information is summarized in the Channel Capacity section of each reach summary in Appendix A - Reach Summaries.

Each cross-section surveyed is graphically displayed in Appendix E. Superimposed on the cross-sections are the stages of various flows. Only those flows which were contained by one or both banks are included. It is important to consider the limitations of the software applied, and of the hydrologic information used (discussed above), and understand that the stages depicted are estimates which should not be construed as highly accurate. There are many variables which affect river stage which are not accounted for with XSPRO. Furthermore, XSPRO is a Manning's roughness based analysis tool and therefore the output of the analysis is strongly dependent upon the roughness values selected for input. While these were based on field observations, it should be noted that small errors in roughness values can significantly affect the data output.

For those flows which exceeded one bank before the other, XSPRO assumes a vertical containing wall at the margin of the cross-section on the bank that is breached first. Consequently, for these flows, the depicted stage is likely higher than in reality, as these flows may disperse to a greater extent than the analysis tool models them. In such a scenario, the actual stage contained by one bank, after the other is breached, is likely lower than depicted. This means that the channel may, in fact, be containing less than depicted flows on one bank.

All output from this analysis is found in Table 2. While stage-discharge relationships are useful for geomorphic analysis, the hydraulic information presented can be utilized for more in depth assessments of channel conditions that will affect any design of an in-channel project. Again, note that the values here are intended to provide only a preview of what hydraulic conditions may be on site.

Twenty additional cross-sections were surveyed on the East Fork at locations that had been surveyed by the SCS in 1982. At the time of this report, analysis of these sites has not been completed.

Table 2. Selected flow characteristics for 40 surveyed cross-sections on the Carson River by reach.

Carson River Cross-Sections
Hydraulic Summary Sheet
Prepared by Inter-Fluve, Inc.
11/19/96

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
C2-1a	1.25-Year	3.70	357.8	193.4	192.3	1.9	1.9	0.001	0.022	3.1	1,117	51.97	0.12	0.23	131.50	0.40	3.80
	2-Year	4.80	597	246.2	244	2.4	2.4	0.001	0.022	3.8	2,293	50.83	0.15	0.30	339.75	0.43	
	5-Year	6.40	1023.2	273.3	269	3.7	3.8	0.001	0.021	5.2	5,348	42.03	0.23	0.40	1228.43	0.47	
	10-Year	7.60	1347.2	276.8	271	4.9	5	0.001	0.021	6.3	8,550	35.66	0.31	0.47	2595.10	0.50	
	25-Year	9.30	1811.4	282.9	275.1	6.4	6.6	0.001	0.02	7.9	14,230	29.58	0.40	0.58	5714.87	0.54	
	50-Year	10.80	2226.8	288.3	278.7	7.7	8	0.001	0.02	9.1	20,336	25.81	0.48	0.67	9736.39	0.57	
C2-1b	1.25-Year	6.10	336.6	136.8	126.5	2.5	2.7	0.0006	0.02	3.3	1,112	20.74	0.09	0.23	103.97	0.35	5.40
	2-Year	7.50	523.4	152	139.7	3.4	3.7	0.0006	0.019	4.4	2,284	18.63	0.13	0.28	293.16	0.40	
	5-Year	9.60	931.2	248.7	234.4	3.7	4	0.0006	0.016	5.6	5,244	24.42	0.14	0.36	722.38	0.49	
	10-Year	11.10	1291.8	265.5	249.7	4.9	5.2	0.0006	0.016	6.6	8,497	22.50	0.18	0.42	1564.12	0.51	
C2-2	1.25-Year	3.50	366	143.9	142.8	2.5	2.6	0.0003	0.014	3.1	1,119	40.80	0.05	0.07	53.10	0.34	5.20
	2-Year	4.80	560.2	154.7	152.9	3.6	3.7	0.0003	0.014	4.1	2,295	31.85	0.07	0.09	154.79	0.38	
	5-Year	7.00	902.7	161.8	158.5	5.6	5.7	0.0003	0.013	5.9	5,296	22.64	0.10	0.13	558.33	0.44	
C2-3a	1.25-Year	4.40	309.6	113.3	111.6	2.7	2.8	0.0005	0.018	3.5	1,091	25.36	0.08	0.14	91.28	0.37	5.60
	2-Year	5.60	518.5	149.5	146.7	3.5	3.5	0.0005	0.017	4.4	2,304	26.20	0.11	0.17	249.13	0.41	
	5-Year	7.70	838.5	180.2	175.9	4.7	4.8	0.0005	0.015	6.2	5,207	22.84	0.15	0.24	762.34	0.50	
	10-Year	9.30	1225.1	305.9	300.5	4	4.1	0.0005	0.012	6.9	8,486	32.31	0.12	0.29	1054.96	0.60	
C2-3b	1.25-Year	4.50	311	102.7	101.2	3	3.1	0.0003	0.015	3.6	1,123	22.49	0.06	0.08	62.88	0.36	6.20
	2-Year	6.30	509.2	128.5	126.2	4	4	0.0003	0.014	4.5	2,298	20.03	0.07	0.12	171.58	0.40	
C3-1a	1.25-Year	4.60	255.3	81.3	78.7	3.1	3.2	0.001	0.024	4.3	1,098	17.11	0.19	0.29	212.36	0.42	6.40
	2-Year	5.90	474.6	167.3	163.4	2.8	2.9	0.001	0.02	4.8	2,262	27.69	0.17	0.37	398.03	0.50	
	5-Year	8.00	825.3	175.8	169.8	4.7	4.9	0.001	0.021	6.4	5,308	21.23	0.29	0.50	1549.08	0.51	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
C3-1b	1.25-Year	5.10	250.4	121.4	118.5	2.1	2.1	0.001	0.017	4.5	1,118	23.24	0.13	0.32	147.66	0.55	4.20
	2-Year	6.60	429.8	125.2	120.7	3.4	3.6	0.001	0.02	5.3	2,295	18.29	0.21	0.41	483.29	0.49	
	5-Year	10.10	605.4	82	73.8	7.4	8.2	0.001	0.02	8.8	5,300	7.31	0.46	0.63	2460.04	0.54	
C3-3a	1.25-Year	4.00	322.5	121.3	120.2	2.7	2.7	0.0004	0.018	3.4	1,096	30.05	0.07	0.10	73.90	0.36	5.40
	2-Year	5.40	494.4	127.2	125.3	3.9	3.9	0.0004	0.017	4.7	2,301	23.20	0.10	0.13	226.20	0.42	
	5-Year	7.80	857.6	234	230	3.7	3.7	0.0004	0.012	6.3	5,394	29.49	0.09	0.19	498.97	0.58	
	10-Year	9.20	1321.8	394.3	389.3	3.4	3.4	0.0004	0.011	6.3	8,369	42.32	0.08	0.23	706.69	0.60	
	25-Year	10.90	2068.2	484.1	476.7	4.3	4.3	0.0004	0.012	6.8	14,155	43.73	0.11	0.27	1509.44	0.58	
C3-3b	1.25-Year	3.80	299.8	103.3	101.9	2.9	2.9	0.0004	0.017	3.7	1,095	26.82	0.07	0.09	80.29	0.38	5.80
	2-Year	5.40	471.1	125	122.4	3.8	3.8	0.0004	0.015	5	2,346	22.67	0.09	0.13	223.41	0.45	
	5-Year	7.80	894.2	278.6	273.8	3.2	3.3	0.0004	0.011	5.9	5,315	35.10	0.08	0.19	421.39	0.57	
	10-Year	9.20	1279	282.4	275.6	4.5	4.6	0.0004	0.013	6.5	8,360	29.96	0.11	0.23	933.77	0.53	
C5-1	1.25-Year	4.50	259.6	91.8	90.8	2.8	2.9	0.001	0.023	4	1,028	20.18	0.17	0.28	181.43	0.41	5.80
	2-Year	6.01	415.9	123.9	122.7	3.4	3.4	0.001	0.02	5.3	2,189	20.42	0.21	0.38	467.66	0.51	
	5-Year	8.01	709.4	165.8	164.4	4.3	4.3	0.001	0.018	6.7	4,719	20.52	0.27	0.50	1275.32	0.57	
	10-Year	9.51	1003.8	209.1	206.3	4.8	4.9	0.001	0.018	7.4	7,477	21.69	0.30	0.59	2224.87	0.59	
	25-Year	11.31	1385.8	222.4	217.7	6.2	6.4	0.001	0.018	8.7	12,039	19.25	0.39	0.71	4664.40	0.61	
C6-1	1.25-Year	3.40	224.7	103	101.4	2.2	2.2	0.0105	0.058	4.4	996	29.82	1.44	2.23	1425.12	0.52	4.40
	2-Year	4.60	380.5	163.9	161.7	2.3	2.4	0.0105	0.048	5.6	2,139	35.15	1.51	3.01	3211.03	0.64	
	5-Year	6.21	702.8	233	229.8	3	3.1	0.0105	0.048	6.7	4,715	37.00	1.97	4.07	9255.54	0.67	
	10-Year	7.11	920.8	256	252.1	3.6	3.7	0.0105	0.047	7.6	6,994	35.46	2.36	4.66	16506.51	0.70	
C6-2	1.25-Year	4.30	316.6	99.6	98.3	3.2	3.2	0.0001	0.01	3.3	1,043	22.86	0.02	0.03	20.86	0.33	6.40
	2-Year	6.01	497.2	130.3	128.3	3.8	3.9	0.0001	0.008	4.3	2,156	21.35	0.02	0.04	50.70	0.38	
	5-Year	8.31	907.3	222.6	220.4	4.1	4.1	0.0001	0.007	5.1	4,648	26.52	0.03	0.05	118.38	0.44	
	10-Year	9.71	1260.9	267.4	265.2	4.7	4.8	0.0001	0.007	5.7	7,168	27.31	0.03	0.06	210.78	0.46	
	25-Year	11.51	1761.2	292.5	290.2	6	6.1	0.0001	0.008	6.5	11,506	25.21	0.04	0.07	428.61	0.46	
C6-4	1.25-Year	2.60	403.2	219.9	218.7	1.8	1.8	0.0003	0.017	2.4	978	84.12	0.03	0.05	32.61	0.32	3.60
	2-Year	3.60	628.1	243.9	242.3	2.6	2.6	0.0003	0.016	3.4	2,120	67.31	0.05	0.07	103.94	0.37	
	5-Year	5.10	1084.5	389.1	386.7	2.8	2.8	0.0003	0.013	4.4	4,725	75.82	0.05	0.10	250.12	0.46	
	10-Year	6.01	1469.8	503.6	500.9	2.9	2.9	0.0003	0.012	4.8	7,108	83.34	0.05	0.11	383.00	0.50	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
	25-Year	7.21	2108.7	551.4	548.1	3.8	3.8	0.0003	0.012	5.5	11,500	76.02	0.07	0.13	825.02	0.50	
	50-Year	8.00	2545.6	558.2	554	4.6	4.6	0.0003	0.013	6	15,250	69.25	0.09	0.15	1315.24	0.49	
C6-5	1.25-Year	3.50	365.1	220.4	219.3	1.7	1.7	0.0008	0.022	2.6	963	62.66	0.08	0.17	80.56	0.35	3.40
	2-Year	4.50	596.2	244.5	243	2.4	2.5	0.0008	0.022	3.5	2,110	54.00	0.12	0.22	250.00	0.39	
	5-Year	5.75	955.9	342.9	340.8	2.8	2.8	0.0008	0.018	4.6	4,374	59.27	0.14	0.29	614.61	0.48	
	10-Year	6.75	1349.8	489.9	487.5	2.8	2.8	0.0008	0.016	5.1	6,917	72.22	0.14	0.34	962.22	0.54	
	25-Year	8.00	2051.3	636.6	632.6	3.2	3.2	0.0008	0.016	5.6	11,564	79.08	0.16	0.40	1835.02	0.55	
C6-6	1.25-Year	2.60	369.6	306.4	305.7	1.2	1.2	0.0056	0.045	2.8	1,042	117.58	0.42	0.91	433.95	0.45	2.40
	2-Year	3.30	585.1	310	308.6	1.9	1.9	0.0056	0.046	3.7	2,178	93.52	0.66	1.15	1437.34	0.47	
	5-Year	4.30	895.6	314.3	311.8	2.8	2.9	0.0056	0.044	5.1	4,531	72.51	0.98	1.50	4469.05	0.53	
	10-Year	5.10	1153	353.9	350.6	3.3	3.3	0.0056	0.04	6.1	7,009	68.75	1.15	1.78	8110.46	0.59	
	25-Year	6.21	1600.9	467.4	463	3.4	3.5	0.0056	0.036	7.1	11,415	74.56	1.19	2.17	13504.36	0.67	
	50-Year	7.01	2024.3	558.3	553.1	3.6	3.7	0.0056	0.034	7.7	15,556	78.90	1.26	2.45	19608.33	0.71	
C7-1	1.25-Year	3.90	293.3	173.2	171.3	1.7	1.7	0.0027	0.032	3.5	1,019	43.92	0.29	0.66	294.02	0.47	3.40
	2-Year	4.90	494.1	212.1	209.7	2.3	2.4	0.0027	0.032	4.3	2,108	42.80	0.39	0.83	823.30	0.49	
	5-Year	6.21	770.7	218.3	215.3	3.5	3.6	0.0027	0.032	5.6	4,296	34.67	0.59	1.05	2545.01	0.52	
	10-Year	7.21	990.1	238.5	235.2	4.2	4.2	0.0027	0.03	6.6	6,530	32.62	0.71	1.21	4624.03	0.57	
	25-Year	8.41	1286.9	273.8	270.1	4.7	4.8	0.0027	0.028	7.8	9,997	32.12	0.79	1.42	7948.51	0.63	
	50-Year	9.41	1580	324.2	320.4	4.9	4.9	0.0027	0.026	8.6	13,541	34.05	0.83	1.59	11217.60	0.68	
	100-Year	9.51	511.5	69.6	68	7.4	7.5	0.0027	0.03	9.8	5,020	7.15	1.25	1.60	6249.59	0.63	
C7-2	1.25-Year	4.90	322.4	104.5	102.3	3.1	3.2	0.0001	0.01	3.2	1,037	20.88	0.02	0.03	19.96	0.32	6.40
	2-Year	6.41	567.3	215.4	211.7	2.6	2.7	0.0001	0.008	3.8	2,132	33.03	0.02	0.04	34.97	0.41	
	5-Year	8.21	1028.1	299.6	294.3	3.4	3.5	0.0001	0.008	4.3	4,448	35.85	0.02	0.05	93.79	0.41	
	10-Year	9.41	1388.9	311.1	304.7	4.5	4.6	0.0001	0.008	5	6,894	32.38	0.03	0.06	195.00	0.41	
	25-Year	10.45	1713.1	342.8	335	5	5.1	0.0001	0.008	5.6	9,584	32.06	0.03	0.07	299.31	0.44	
C7-3	1.25-Year	4.40	321.3	177.1	176.6	1.8	1.8	0.0004	0.014	3.1	996	40.14	0.04	0.11	44.75	0.41	3.60
	2-Year	5.51	524.7	193.5	192.8	2.7	2.7	0.0004	0.015	3.9	2,048	34.99	0.07	0.14	137.91	0.42	
	5-Year	7.21	868.6	210.1	209	4.1	4.2	0.0004	0.015	5.2	4,542	28.99	0.10	0.18	462.22	0.45	
	10-Year	8.51	1156.1	250.3	248.8	4.6	4.6	0.0004	0.014	5.9	6,863	29.24	0.11	0.21	783.16	0.48	
	25-Year	10.01	1567.3	285.4	282.2	5.5	5.6	0.0004	0.014	6.8	10,718	28.19	0.14	0.25	1463.08	0.51	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
C8-1	1.25-Year	3.20	336.7	137.7	136.9	2.4	2.5	0.0002	0.013	2.9	970	42.78	0.03	0.04	29.25	0.32	5.00
	2-Year	4.50	518.8	144.3	143	3.6	3.6	0.0002	0.012	4	2,058	31.78	0.04	0.06	93.23	0.37	
	5-Year	6.41	818.7	301.3	298.9	2.7	2.7	0.0002	0.008	5.3	4,364	46.63	0.03	0.08	146.21	0.57	
	10-Year	7.51	1222.9	420.7	417.6	2.9	2.9	0.0002	0.008	5.3	6,467	55.61	0.04	0.09	234.57	0.55	
	25-Year	8.81	1804.5	458.1	454.8	3.9	4	0.0002	0.009	5.7	10,229	51.62	0.05	0.11	500.62	0.50	
	50-Year	9.71	2216.3	463.4	459.1	4.8	4.8	0.0002	0.01	6.1	13,614	47.28	0.06	0.12	809.87	0.49	
	100-Year	10.61	2631.7	468.4	463.1	5.6	5.7	0.0002	0.01	6.7	17,587	43.65	0.07	0.13	1232.29	0.49	
C8-2	1.25-Year	3.80	311.3	131	130.1	2.4	2.4	0.0005	0.018	3.3	1,027	34.24	0.07	0.12	76.92	0.38	4.80
	2-Year	5.00	471.3	137.5	136.1	3.4	3.5	0.0005	0.017	4.4	2,071	27.22	0.11	0.16	219.98	0.41	
	5-Year	6.81	723.4	145.9	143.7	5	5	0.0005	0.016	5.9	4,283	21.10	0.16	0.21	665.82	0.46	
	10-Year	8.21	929	152.4	149.6	6.1	6.2	0.0005	0.016	7	6,516	18.22	0.19	0.26	1237.65	0.50	
C9-1a	1.25-Year	4.20	398.3	175.2	170.8	2.3	2.3	0.0001	0.01	2.5	994	40.67	0.01	0.03	14.29	0.29	4.60
	2-Year	5.30	587.5	178.4	173.2	3.3	3.4	0.0001	0.01	3.4	1,993	32.68	0.02	0.03	41.13	0.32	
	5-Year	6.90	867.8	207.1	200.6	4.2	4.3	0.0001	0.008	4.6	3,980	29.07	0.03	0.04	104.62	0.39	
C9-1b	1.25-Year	3.60	288.7	135.5	134.8	2.1	2.1	0.0003	0.014	3.2	929	37.44	0.04	0.07	36.32	0.39	4.20
	2-Year	4.90	469.9	145.5	144.3	3.2	3.3	0.0003	0.014	4.2	1,950	29.45	0.06	0.09	118.23	0.41	
	5-Year	6.70	744.1	161.9	160.3	4.6	4.6	0.0003	0.014	5.4	3,983	23.93	0.09	0.13	346.01	0.44	
	10-Year	7.90	942.8	172.8	171	5.5	5.5	0.0003	0.014	6.1	5,759	21.65	0.10	0.15	592.13	0.46	
	25-Year	9.40	1214.5	197.8	195.6	6.1	6.2	0.0003	0.013	7.1	8,644	20.81	0.11	0.18	984.67	0.50	
	50-Year	10.40	1418.9	216.3	213.2	6.6	6.7	0.0003	0.012	7.8	11,082	20.50	0.12	0.19	1367.40	0.53	
C9-1c	1.25-Year	4.30	345.8	195	192.7	1.8	1.8	0.0001	0.009	2.8	980	44.81	0.01	0.03	10.88	0.37	3.60
	2-Year	5.40	558	196.2	193.1	2.8	2.9	0.0001	0.01	3.5	1,961	35.76	0.02	0.03	34.12	0.36	
	5-Year	7.00	867.4	197.8	193.6	4.4	4.5	0.0001	0.01	4.7	4,069	27.66	0.03	0.04	111.93	0.39	
	10-Year	8.00	1061.3	198.9	194	5.3	5.5	0.0001	0.01	5.4	5,762	24.25	0.03	0.05	189.54	0.41	
C9-1d	1.25-Year	4.80	327.6	128.2	126.2	2.6	2.6	0.0001	0.012	2.9	940	26.29	0.02	0.03	15.41	0.32	5.20
	2-Year	6.10	504.8	173	170.2	2.9	3	0.0001	0.01	3.8	1,925	27.90	0.02	0.04	34.71	0.39	
	5-Year	7.90	871.5	237.8	233.7	3.7	3.7	0.0001	0.009	4.6	4,022	29.58	0.02	0.05	92.56	0.42	
	10-Year	8.90	1113.6	268.4	263.9	4.1	4.2	0.0001	0.009	5.2	5,745	29.65	0.03	0.06	148.15	0.45	
	25-Year	10.20	1607.2	451.1	445.8	3.6	3.6	0.0001	0.008	5.4	8,706	43.71	0.02	0.06	194.96	0.50	
	50-Year	10.90	1925.7	469.6	464.1	4.1	4.1	0.0001	0.008	5.6	10,875	42.58	0.03	0.07	275.90	0.49	
	100-Year	11.70	2305.3	490.8	484.9	4.7	4.8	0.0001	0.008	6	13,777	41.44	0.03	0.07	405.66	0.48	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
C9-1e	1.25-Year	4.50	289	120	118.4	2.4	2.4	0.0002	0.012	3.3	965	26.31	0.03	0.06	28.57	0.38	4.80
	2-Year	5.90	465.8	139.4	137.2	3.3	3.4	0.0002	0.011	4.3	1,983	23.25	0.04	0.07	82.49	0.41	
	5-Year	7.60	819	282.1	278	2.9	2.9	0.0002	0.009	4.8	3,958	36.58	0.04	0.09	142.28	0.50	
	10-Year	8.60	1102.9	299.7	295.2	3.7	3.7	0.0002	0.01	5.3	5,791	34.33	0.05	0.11	269.92	0.49	
C10-1a	1.25-Year	4.00	312.3	142.6	138.5	2.2	2.3	0.0005	0.018	3.1	974	34.63	0.07	0.12	66.45	0.36	4.60
	2-Year	5.20	480	146.5	141.1	3.3	3.4	0.0005	0.017	4.2	2,020	27.13	0.10	0.16	207.57	0.40	
	5-Year	6.90	775.6	235.4	228	3.3	3.4	0.0005	0.014	5.1	3,929	33.04	0.10	0.22	407.26	0.49	
	10-Year	8.00	1038.1	289	280	3.6	3.7	0.0005	0.014	5.6	5,840	35.00	0.11	0.25	652.96	0.51	
C10-b	1.25-Year	3.90	291.2	132.3	131.2	2.2	2.2	0.0014	0.028	3.4	999	33.64	0.19	0.34	190.29	0.40	4.40
	2-Year	5.00	437.8	137	135.3	3.2	3.2	0.0014	0.027	4.6	2,017	27.06	0.28	0.44	562.98	0.45	
	5-Year	6.60	658.9	143.8	141.2	4.6	4.7	0.0014	0.025	6.2	4,067	21.39	0.40	0.58	1641.65	0.50	
C10-1c	1.25-Year	3.20	268.9	133.8	131.1	2	2.1	0.0014	0.025	3.6	965	40.97	0.17	0.28	169.14	0.44	4.20
	2-Year	4.30	414.6	137.7	133.9	3	3.1	0.0014	0.025	4.6	1,927	31.14	0.26	0.38	499.83	0.46	
	5-Year	6.00	645.9	143.8	138.2	4.5	4.7	0.0014	0.025	6.3	4,044	23.03	0.39	0.52	1599.67	0.51	
	10-Year	6.90	789.7	196.5	190	4	4.2	0.0014	0.021	6.9	5,477	27.54	0.35	0.60	1904.07	0.59	
C10-2a	1.25-Year	3.80	292.2	172.8	169.6	1.7	1.7	0.0008	0.018	3.3	960	44.63	0.08	0.19	81.83	0.45	3.40
E2-1	1.25-Year	4.00	249.5	109.7	106.9	2.3	2.3	0.0135	0.055	5.5	1,366	26.73	1.94	3.37	2658.76	0.64	4.60
	2-Year	5.00	364.8	125.6	122.3	2.9	3	0.0135	0.055	6.5	2,355	24.46	2.44	4.21	5792.75	0.66	
	5-Year	6.50	566.1	149.4	146	3.8	3.9	0.0135	0.053	7.9	4,495	22.46	3.20	5.48	14316.02	0.70	
	10-Year	7.50	719.3	162.4	158.8	4.4	4.5	0.0135	0.053	8.9	6,385	21.17	3.71	6.32	23728.54	0.74	
	25-Year	8.80	933.5	174.7	170.7	5.3	5.5	0.0135	0.052	10.1	9,432	19.40	4.46	7.41	42094.94	0.76	
	50-Year	9.90	1126.8	185.2	180.8	6.1	6.2	0.0135	0.052	11.1	12,530	18.26	5.14	8.34	64271.44	0.79	
	100-Year	11.00	1332.6	203	198.3	6.6	6.7	0.0135	0.05	12.1	16,164	18.03	5.56	9.27	89649.42	0.82	
E2-2	1.25-Year	4.00	320.9	146.2	145.3	2.2	2.2	0.0044	0.04	4.2	1,344	36.33	0.60	1.10	814.10	0.50	4.40
	2-Year	5.00	488.4	188.2	187	2.6	2.6	0.0044	0.039	4.8	2,361	37.40	0.71	1.37	1673.51	0.52	
	5-Year	6.30	741.6	203.9	202.5	3.6	3.7	0.0044	0.039	6.1	4,516	32.14	0.99	1.73	4471.36	0.56	
	10-Year	7.20	928.7	214.8	213.2	4.3	4.4	0.0044	0.038	6.9	6,436	29.61	1.18	1.98	7565.37	0.58	
	25-Year	8.30	1170.9	231	229.3	5.1	5.1	0.0044	0.037	8	9,339	27.63	1.40	2.28	13116.48	0.62	
	50-Year	9.20	1386.8	252.2	250.4	5.5	5.5	0.0044	0.035	8.9	12,353	27.22	1.51	2.53	18638.19	0.67	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
E2-3	1.25-Year	4.70	280.3	100.3	99.2	2.8	2.8	0.003	0.034	4.8	1,351	21.11	0.52	0.88	705.23	0.51	5.60
	2-Year	6.10	464.6	161.6	160.1	2.9	2.9	0.003	0.033	5	2,341	26.25	0.54	1.14	1261.11	0.52	
	5-Year	7.50	690.8	164.8	163	4.2	4.2	0.003	0.033	6.5	4,497	21.73	0.79	1.40	3530.37	0.56	
	10-Year	8.50	854.8	167.1	165	5.1	5.2	0.003	0.032	7.6	6,457	19.41	0.95	1.59	6202.32	0.59	
	25-Year	9.80	1071.7	173.8	171.5	6.2	6.2	0.003	0.031	8.9	9,547	17.50	1.16	1.83	11070.34	0.63	
	50-Year	10.80	1249.8	187.1	184.7	6.7	6.8	0.003	0.029	9.9	12,413	17.10	1.25	2.02	15518.74	0.67	
E2-4	1.25-Year	4.70	470.7	265.5	262.3	1.8	1.8	0.0018	0.032	2.9	1,349	55.81	0.20	0.53	275.98	0.38	3.60
	2-Year	5.40	657.5	275	271.4	2.4	2.4	0.0018	0.031	3.7	2,415	50.26	0.27	0.61	655.79	0.42	
	5-Year	6.40	932.5	281.4	277.4	3.3	3.4	0.0018	0.029	4.8	4,490	43.34	0.37	0.72	1659.06	0.46	
	10-Year	7.10	1127.8	285.1	280.7	4	4	0.0018	0.028	5.6	6,292	39.54	0.45	0.80	2837.51	0.49	
	25-Year	8.30	1481.9	312	306.1	4.8	4.8	0.0018	0.027	6.5	9,623	36.88	0.54	0.93	5193.15	0.52	
	50-Year	9.10	1728.9	319.1	311.3	5.4	5.6	0.0018	0.027	7.2	12,523	34.21	0.61	1.02	7550.11	0.54	
	100-Year	10.00	2011.7	327	317.2	6.2	6.3	0.0018	0.026	8	16,189	31.72	0.70	1.12	11207.33	0.56	
E4-1	1.25-Year	5.70	320.7	112.1	109	2.9	2.9	0.0015	0.028	4.2	1,353	19.12	0.27	0.53	365.61	0.43	5.80
	2-Year	7.80	561.8	124.6	120.7	4.5	4.7	0.0015	0.026	6.1	3,432	15.47	0.42	0.73	1443.44	0.50	
	5-Year	9.20	746.6	149.9	145.3	5	5.1	0.0015	0.024	7	5,242	15.79	0.47	0.86	2445.86	0.55	
	10-Year	9.90	853.2	164.3	159.3	5.2	5.4	0.0015	0.023	7.5	6,375	16.09	0.49	0.93	3114.52	0.57	
	25-Year	10.80	999.5	170.4	165	5.9	6.1	0.0015	0.023	8.2	8,183	15.28	0.55	1.01	4526.10	0.59	
	50-Year	11.40	1099.5	173.9	168.4	6.3	6.5	0.0015	0.023	8.7	9,530	14.77	0.59	1.07	5640.67	0.60	
	100-Year	12.00	1201.5	177.5	171.7	6.8	7	0.0015	0.023	9.1	10,985	14.31	0.64	1.12	6959.05	0.61	
E4-1b	1.25-Year	4.10	305.7	116.4	114.3	2.6	2.7	0.0015	0.024	4.6	1,398	27.88	0.24	0.38	342.22	0.49	5.40
	2-Year	6.10	547.7	128.4	125.6	4.3	4.4	0.0015	0.024	6.2	3,412	20.59	0.40	0.57	1366.72	0.52	
	5-Year	7.50	747.5	165.2	162	4.5	4.6	0.0015	0.023	7	5,240	21.60	0.42	0.70	2203.93	0.58	
	10-Year	8.20	863.5	170.9	167.4	5.1	5.2	0.0015	0.023	7.5	6,471	20.41	0.48	0.77	3091.50	0.58	
	25-Year	9.10	1015.8	175.1	171.2	5.8	5.9	0.0015	0.023	8.2	8,292	18.81	0.54	0.85	4521.95	0.59	
	50-Year	9.60	1102	177.5	173.4	6.2	6.4	0.0015	0.023	8.5	9,408	18.06	0.58	0.90	5435.86	0.59	
	100-Year	10.20	1206.8	180.3	175.9	6.7	6.9	0.0015	0.023	9	10,845	17.25	0.63	0.95	6811.28	0.60	
E4-2	1.25-Year	3.50	364.4	170.3	169.5	2.1	2.1	0.0047	0.045	3.8	1,373	48.43	0.62	1.03	852.83	0.46	4.20
	2-Year	5.00	627	181.6	180.4	3.5	3.5	0.0047	0.042	5.6	3,515	36.08	1.03	1.47	3604.18	0.53	
	5-Year	5.90	792.1	188.2	186.6	4.2	4.2	0.0047	0.041	6.6	5,237	31.63	1.23	1.73	6439.55	0.57	
	10-Year	6.50	905.3	192.5	190.8	4.7	4.7	0.0047	0.04	7.2	6,561	29.35	1.38	1.91	8984.74	0.59	

X-Sec Name	Return Interval	Depth ft	Flow Area ft^2	Wet. Perim. ft	Top Width ft	Hyd. Rad. ft	Avg. Depth ft	Slope ft/ft	"n"	Avg. Vel. ft/s	Dschg cfs	W/D	Avg. Shear lb/ft^2	Max. Shear lb/ft^2	Stream Power foot-lbs/s	Froude No.	2* Bankfull Depth ft
	25-Year	7.20	1040.6	197.6	195.6	5.3	5.3	0.0047	0.039	8	8,285	27.17	1.55	2.11	12939.94	0.61	
	50-Year	7.70	1139.3	201.2	199.1	5.7	5.7	0.0047	0.039	8.5	9,632	25.86	1.67	2.26	16188.79	0.63	
	100-Year	8.60	1344.2	245.2	242.8	5.5	5.5	0.0047	0.039	8.2	11,063	28.23	1.61	2.52	17779.64	0.62	
E5-1a	1.25-Year	4.70	470.2	216.4	215.1	2.2	2.2	0.0003	0.013	3	1,428	45.77	0.04	0.09	58.09	0.36	4.40
	2-Year	6.20	803.3	231	229.2	3.5	3.5	0.0003	0.013	4.2	3,374	36.97	0.07	0.12	221.06	0.40	
	5-Year	7.30	1061.1	241.8	239.6	4.4	4.4	0.0003	0.013	5	5,326	32.82	0.08	0.14	437.00	0.42	
	10-Year	7.80	1182.1	246.6	244.3	4.8	4.8	0.0003	0.012	5.4	6,357	31.32	0.09	0.15	573.58	0.43	
	25-Year	8.60	1380.6	254.5	251.9	5.4	5.5	0.0003	0.012	5.9	8,193	29.29	0.10	0.16	823.42	0.44	
	50-Year	9.10	1507.7	259.4	256.6	5.8	5.9	0.0003	0.012	6.3	9,457	28.20	0.11	0.17	1031.31	0.46	
	100-Year	9.60	1637.2	264.3	261.3	6.2	6.3	0.0003	0.012	6.6	10,810	27.22	0.12	0.18	1254.13	0.46	
E5-1b	1.25-Year	5.10	493.1	245.1	244	2	2	0.0003	0.013	2.8	1,394	47.84	0.04	0.10	51.69	0.35	4.00
	2-Year	6.60	864.4	253.2	251.1	3.4	3.4	0.0003	0.013	4.1	3,526	38.05	0.06	0.12	225.57	0.39	
	5-Year	7.50	1092.3	258.1	255.3	4.2	4.3	0.0003	0.013	4.8	5,254	34.04	0.08	0.14	412.23	0.41	
	10-Year	8.00	1220.6	260.9	257.7	4.7	4.7	0.0003	0.013	5.2	6,352	32.21	0.09	0.15	558.45	0.42	
	25-Year	8.80	1428.3	265.2	261.5	5.4	5.5	0.0003	0.012	5.8	8,311	29.72	0.10	0.16	837.43	0.44	
	50-Year	9.20	1533.2	267.4	263.4	5.7	5.8	0.0003	0.012	6.1	9,382	28.63	0.11	0.17	997.95	0.45	
	100-Year	9.70	1665.5	270.1	265.7	6.2	6.3	0.0003	0.012	6.5	10,805	27.39	0.12	0.18	1256.48	0.46	
E6-1a	1.25-Year	8.40	307.5	140.1	135	2.2	2.3	0.0005	0.013	4.4	1,356	16.07	0.07	0.26	92.87	0.51	4.60
	2-Year	10.60	699.3	219.2	212.4	3.2	3.3	0.0005	0.015	5	3,473	20.04	0.10	0.33	349.09	0.49	
	5-Year	11.70	935.2	224	216.5	4.2	4.3	0.0005	0.016	5.7	5,320	18.50	0.13	0.37	698.53	0.48	
	10-Year	12.30	1065.8	226.7	218.7	4.7	4.9	0.0005	0.016	6.1	6,515	17.78	0.15	0.38	953.36	0.49	
	25-Year	13.10	1242	230.2	221.7	5.4	5.6	0.0005	0.016	6.7	8,309	16.92	0.17	0.41	1401.99	0.50	
	50-Year	13.60	1353.3	232.4	223.5	5.8	6.1	0.0005	0.016	7.1	9,543	16.43	0.18	0.42	1738.74	0.51	
	100-Year	14.05	1459.3	269.3	260.2	5.4	5.6	0.0005	0.015	7.4	10,771	18.52	0.17	0.44	1819.39	0.55	
E6-1b	1.25-Year	6.80	310.4	96.2	91.2	3.2	3.4	0.0002	0.011	4.4	1,352	13.41	0.04	0.08	54.54	0.42	6.80
	2-Year	9.50	561.6	102.7	94.9	5.5	5.9	0.0002	0.011	6.1	3,424	9.99	0.07	0.12	235.14	0.44	
	5-Year	11.20	727.5	120.3	110.9	6	6.6	0.0002	0.01	7.2	5,213	9.90	0.07	0.14	392.22	0.49	

APPENDIX C - COTTONWOOD REGENERATION

Reproductive Biology of Fremont Cottonwood

Fremont cottonwood (*Populus fremonti*), like other cottonwood species of the western US, is a pioneering species that requires moist, newly deposited alluvium, or recently disturbed soil exposed to full sunlight. In general, same-age stands (cohorts) establish from seed on point bars, side bars, mid-channel bars and islands. Because of these seed germination requirements, cottonwoods are considered a successional species and do not represent a self-sustaining plant community.

Many mature stands of large cottonwoods appear to have limited regeneration, because seedling to sapling-sized trees are scattered or absent. It is important to understand that such scattered seedlings and saplings in a mature stand represent stump sprouts (asexual reproduction) and not establishment by seed (sexual reproduction)(Hansen 1995). Asexual reproduction helps to prolong the life of a mature stand but will not maintain the stand, and in fact is only effective for the first 20-25 years of the trees' lives (Read 1958). In time, mature stands will be replaced by later successional stages or other vegetation types (Hansen 1995).

Cottonwood stands consist of spatially separate, same-age plants that grow in linear bands parallel to primary and secondary channels (Stromberg et al. 1994). The youngest trees are almost always closest to the channel, while the older trees can be found on floodplains several hundreds of feet from the primary channel. Younger trees typically occur on shallow groundwater sites and the oldest trees on elevated terraces higher on the floodplain. These patterns occur because mature trees have greater rooting depths than younger trees, and because floodplains aggrade with age (Brady 1985). Although mature cottonwoods can tolerate intermediate water table depths (up to 5 m) continued reproduction requires short periods in spring in which the water tables are very near the floodplain surface, followed by a period in which water tables decline to a depth no greater than 1 m by the summer's end (Stromberg et al. 1994).

Cottonwoods frequently live 100 to 150 years although they have been reported to live up to 200 (Shaw 1976, Stromberg 1991) and 300 years (Merigliano 1996). Although reported ages vary by species and geographic region, the process by which cottonwoods establish is consistent. In contrast to woody species that regenerate regularly, cottonwood recruitment that leads to long-term survival is episodic, as demonstrated by the fact that mature trees in the same stand tend to be the same age (Read 1958, Clayton 1996). The time interval between successful establishment of mature stands can be considerable, even though tremendous seedling germination can be observed in consecutive years (Clayton 1996).

Bradley and Smith (1986) reported that stand of Great Plains cottonwood (*Populus deltoides*) established on a site in southern Alberta about once every five years on average. Baker (1990) observed that narrowleaf cottonwood (*Populus angustifolia*) recruitment occurred about once every 10-15 years on the Animas River in southwestern Colorado. On the Hassayampa River in Arizona establishment of mature Fremont cottonwood cohorts was observed once every 12 years (Stromberg et al 1991). An even larger interval of successful establishment was found by Everitt (1995), who noted that only one Fremont cottonwood cohort regenerated by seed survived the past century along an approximately 40 km reach of the Fremont River in southeastern Utah.

Using models based on data from the Animas River in Colorado, Baker (1990) found that seed germination (but not long-term seedling survival) was successful in cool, wet years (especially with a cool and wet fall) and these conditions occurred with a recurrence interval of 3-4 years between 1914 and 1984. However, stand origin years (when seedlings established and then survived long enough to grow and reproduce) were associated with years of both high spring flows and high fall discharges resulting from fall thunderstorms (Baker 1990). This supports Noble's (1979) assertion that a sustained river elevation throughout the growing season contributes to seedling survival (Clayton 1996). Hydrologic conditions suitable for stand origin had a mean interval of 12 years (Baker 1990).

As suggested by longer time intervals between stand origins than between good seedling years, seedling survival is limited by many factors in addition to bare and moist substrate (Clayton 1996). For example, seedlings closest to the active channel may have access to more moisture during the growing season, seedlings in this location may be exposed to considerable natural disturbances during other times of the year. Seedling survival is dependent on "hydrographically quiet" (Everitt 1995) conditions without extreme high or low flows in the few years following establishment. Ice scour during the winter can uproot young seedlings and break off their tops (Clayton 1996). Additionally alluvial bars must not be scoured away by subsequent high flows (Shaw 1991) and be able to survive sediment deposition in the first years following establishment (Bradley and Smith 1986). Finally, seedlings must be able to tolerate livestock or wildlife browsing, grazing and trampling.

The general health of cottonwood population can be assessed by observing the relative abundance and aereal extent of several age classes. Knowledge of the age class structure of a plant community can be used to interpret trends in population replacement with time, to reconstruct the periodicity of reproductive success of a population, and to reconstruct population response to disturbance such as grazing, fire, mining or flooding (Barbor et al. 1986). Several age classes of cottonwoods are typically recognized. These include the seedling, the intermediate, mature, and decadent/dead age classes.

Seedling Age Class. The seedling age class consists of a cottonwood plant sprouted from seed and is in its first season of growth. These plants are generally less than 0.5 m in height and less than 2 cm in diameter. Cottonwood seeds are extremely small (approximately 1 mm in length), viable for only 2-4 weeks, and are dispersed by wind (Fenner et al 1985). Seed dispersal occurs in the spring and early summer during the period of high flows, and by the time flows begin to recede, most Fremont cottonwood seeds are probably dispersed. Germination of cottonwood seeds is often successful where receding high flows leave a moist, freshly deposited alluvial substrate that lacks competing vegetation.

A study on black cottonwood (*Populus trichocarpa*) seedling germination in western Montana recorded over 1200 seedlings per square meter, but less than one percent of these seedlings survived the first growing season Survival of seedlings was directly correlated with the rate of groundwater decline. For example, during the first three weeks of seedling growth, seedling mortality was observed if the drop in water table was greater than 0.5 cm per day (Clayton 1996). This is slightly less than a laboratory study on Fremont cottonwood in which the mean rate of water table decline for seedling survival was observed to be 0.6 cm per day (Fenner et. al 1984).

Intermediate Age Class. The intermediate age class consists of seedlings and saplings at least one year old and of intermediate size (greater than 0.5 m tall with stems 2 to 15 cm in diameter). This age class ranges from approximately 2-30 years old. Although intermediate age class cottonwoods (and other riparian tree and shrub species) can endure moderate drought stress as the water table recedes, they are very susceptible to mortality during the mid-to late-summer season, especially in low-flow years (Smith et al. 1991) because root systems are not fully developed. If the water table falls below the rooting zone, drought stress occurs. If this continues, will result in seedling mortality.

Mature Age Class. The mature age class consists of cottonwoods that are generally at least 20-30 years old, over 5 m tall, and greater than 20 cm in diameter. The mature age class includes large trees with extensive deep root systems that may be up to 300 years old (Merigliano 1996). Because of the deep roots, this age class is less sensitive to human-induced hydrologic disturbance (Bradley and Smith 1986). However, research (Stromberg 1990) has observed reduced growth, drought stress and mortality in mature stands impacted by excessive groundwater pumping, streamflow diversions, or irregular dam releases.

Decadent/dead Age Class Cottonwoods in the decadent or dead age class are mature trees with dead foliage occupying between 30 to 100 percent of the canopy. Such conditions can be representative of healthy stands which are dying from old age. Alternatively, this condition may be induced prematurely by conditions of anthropogenic origin such as reduced stream flow, groundwater pumping or other sources.

Existing conditions

Along many reaches of the Carson River, germinating Fremont cottonwood seedlings, apparently established in the spring 1996, were widespread. These observations are consistent with the hydrologic and geomorphic conditions of this system. The flow regime is unregulated, so a large winter/spring flood normally occurs, an abundance of sediment is available for transport and subsequent formation of alluvial cottonwood seedbeds, and finally, cottonwood seed is common.

However, and with only a few exceptions, the intermediate age was observed to be severely under-represented. That is, it appears that survival of germinating seedlings is extremely limited, with the result that few cottonwoods stands exist to replace the aging mature tree form commonly observed along the Carson River. Since these mature stands are not self-perpetuating, it is possible that Fremont cottonwood is very gradually being eliminated from the banks and floodplain of the Carson River.

The mature age class of cottonwoods along the Carson River was abundant and healthy. Large, and apparently deep rooted trees were common and few trees were observed that could be characterized as part of the dead or decadent age class.

Hydrologic modifications may explain the lack of the intermediate age class of cottonwoods. Specifically, river stage through the summer months may not gradually recede along the falling limb of the hydrograph. Instead, the gradual recession of flood waters is interrupted by local and large diversions intermittently throughout the dry summer months. These diversions may result in a sudden drop in water tables that juvenile seedlings cannot survive because root growth rates cannot keep up with the falling water table.

Another factor that may explain the lack of intermediate age classes of cottonwood is related to geomorphology. In certain reaches of the Carson River, the channel is heavily incised and floodplains are rarely inundated due to their relative elevation above the channel. In these reaches, hydraulic forces of flood flows are not dissipated by access to wide floodplains. Instead erosive forces remain high because flows are confined by steep banks. Consequently, annual sediment transport and associated bar development is accelerated. In these conditions it appears that bars which provide good conditions for cottonwood establishment in the spring of one year tend to either be so impacted by scour (Shaw 1991) or deposition in the subsequent year that seedlings are unable to survive.

It is also possible that many of the mature stands of cottonwood became established during the mining boom of the 1800's when considerable disturbance of floodplains for mining created ideal conditions for cottonwood establishment (Merigliano - personal communication). If the ages of mature cottonwood stands correspond to known mining history in the area, many stands of mature cottonwoods may be the result of anthropogenic disturbance rather than natural floodplain dynamics. If this could be proven (via dating tree ages though tree coring), the intermediate age classes may not be under-represented, but rather be an effect of the natural episodic nature of cottonwood establishment. Additionally, mature stands occurring on perched floodplains may roughly correspond in age to episodes of channel incision. In this scenario, generation of a stand may have occurred when channel elevations were relatively close to floodplain elevations and mature tree root systems may have grown downward at a rate which kept up with incision and the resulting depression of the water table.

Recommendations

The biggest concern regarding cottonwood establishment along the Carson River is the absence of the intermediate age classes and the inability of seedlings to become established. The intermediate age class provides the critical link between the common germinating seedlings and the extensive, but scattered mature stands. Failure of this age class raises concerns about this important species inability to maintain itself along many reaches of the Carson River. Such a pattern is very common throughout the west, and has been consistently linked to alterations in hydrology.

1. Restore Hydrology

Most reaches of the Carson show an absence of sprout and young cottonwood regeneration. Exceptions to this include the upper reaches of the East Fork and the bottom reaches of the Carson River. Due to the predominance of evidence in the literature that altered hydrology affects cottonwood regeneration and the significant effect of irrigation withdrawals on Carson River hydrology, it is reasonable to conclude that regeneration could be enhanced with greater low-flow discharges. However, due to the importance of irrigation withdrawals to the agricultural community, this may be difficult to accomplish. Prior to efforts to increase low flow discharges, we recommend detailed and site specific study to determine the impacts of irrigation withdrawals on seedling mortality. This could be accomplished by measuring rooting depth simultaneously with water table depths at study locations.

2. Supplemental Planting.

In reaches of the Carson River that support existing stands cottonwoods, but lack the intermediate age classes, a supplemental planting effort may be considered. A large amount of research has been conducted on cottonwood replanting in arid regions, and a review of related literature is advised before any planting efforts are undertaken. A recommended method involves using a backhoe mounted planting tool (known as the "Stinger") that provides a deep (up to 8 feet) hole for the placement of 3-12 inch diameter dormant cottonwood "poles". A critical component of such pole-planting is that enough monitoring, site evaluation, and experimentation be conducted to ensure that proper sites are selected. In addition, it is important to make sure that the base of each cottonwood pole reaches the elevation of the low summer water table. See Hoag (1994) for specific planting details.

3. Restore floodplain.

The majority of reaches of the Carson River were observed to have a floodplain which was perched relative to the channel, as evidenced in the cross-sections and hydraulic analysis. Re-coupling the channel with its floodplain would likely greatly enhance cottonwood regeneration potential. There are two ways to accomplish this: lower the floodplain adjacent to the channel or raise the channel with frequent grade control structures. However, due to the vast scale of such an undertaking, such approaches are unlikely to be practical unless other benefits warrant such measures.

APPENDIX D - PHOTO POINTS

One set of photographs taken at photo points and other reach photos and their negatives has been provided to the WNRC&D.

APPENDIX E - SURVEYED CROSS-SECTIONS

One set of plotted cross-sections with water surfaces at varying intervals for all surveyed reach cross-sections has been provided to the WNRC&D.

APPENDIX F - FIELD FORMS

One set of original field forms has been provided to the WNRC&D.