C-1 REACH SUMMARY

SUB-REACHES: none
LOCATION: Genoa Road to Cradlebaugh Bridge

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

C-1: F5/Mm/III.5

General

Reach C-1 is the uppermost reach of the Carson River and begins at the confluence of the East and West Forks. It is centered in a mile wide band of historic meander scars, sloughs, and swamps. The majority of this reach is a meandering channel, though there are two sections which have been straightened since the 1938 photo series. The bottom two miles of C-1 have shown a small (approximately 10 percent) increase in sinuosity, expressed largely as an increase in amplitude of existing meander bends. The channel is incised throughout the reach, with bank heights up to 12 feet. Point bars are the dominant bar type and are largely unvegetated, consisting of mostly sand and small gravels. Lateral bars and mid channel bars are also present and may be indicative of sediment supply excesses. Due to channel incision and containment of relatively high flows, it is assumed that bars in this reach cannot establish vegetation due to regular and high energy flows on them. Bank vegetation is virtually nonexistent throughout the reach, except in the uppermost section.

No field observation was conducted in the middle portion of the reach. However, review of historic and recent aerial photos reveals a nearly one mile section of meandering channel that has been straightened, between 1938 and 1966. Review of video footage from an aerial survey indicates that this middle reach is similar in geomorphic character to the bottom section. Beyond the significant channelization of one section, the middle portion of C-1 has shown little change in planform characteristics, with only minor shifts in meander bend locations since 1938. There is one diversion structure in C-1, though it was not observed during a ground survey.

The top section of C-1, from Genoa Road to the downstream end of Willow Bend development, is a straightened reach with thick riparian vegetation on its banks and relatively high bank stability. Coincidental with the loss of bank and riparian vegetation, channel banks become unstable. Like the lower sections, this portion is incised.

Channel Capacity

Because no slope measurements were taken during this survey, assessment of channel capacity was not possible.

Land Use

With the exception of ruralization of the uppermost mile and a golf course, grazing is the dominant land use throughout C-1.

Relative Stability

Moderately Unstable to Unstable

General

Planform changes since 1938 have been relatively minor, though lateral migration rates in the bottom portion of the reach may be slightly in excess of normal or stable conditions. This is likely related to the incision of the channel, highly erodable banks and the absence of stabilizing vegetation. Due to channel incision, greater flows are contained within the "bankfull" channel than would otherwise be expected. Consequently, the channel experiences greater hydraulic and erosional forces, on unprotected banks, than in a system that is not incised. This produces excessive bank erosion and excesses in sediment supply to the channel, further exacerbating lateral stability problems.

While all of this reach is incised, there are no indications that the channel is currently degrading its bed. Incision may be greatest below the diversion structure. It appears to have reached a stable grade, with instability problems translated to lateral migration. As discussed above, incision has increased channel capacity and reduced the frequency of overbank flows, consequently concentrating hydraulic forces on the channel rather than dissipating them on the floodplain. An additional effect of this phenomenon, is that the floodplain has a reduced frequency of saturation and therefore moisture, thereby inhibiting riparian vegetation growth adjacent to the channel and on channel banks.

Bank Stability

Upper C-1: stable   Middle and Lower C-1: unstable

With the exception of the well-vegetated and stable banks in the uppermost half mile of C-1, nearly 100 percent of channel banks are unstable. Bank heights range from 8 to 12 feet throughout the observed section. Bank heights in the un-observed section are reportedly up to 20 feet. The majority of these banks are 1:1 or steeper and are being undercut during high flows on both banks, and in some cases on outside bends during low flow conditions. Bank materials are sands and silty loam which fail due to undercutting, forming a sloped bank toe. This bank toe is apparently cleaned out during high flows. Vegetation is absent from most banks, though some bank toes have developed annual vegetation. This vegetation, however, does not add to bank stability as it is washed away on an annual basis. Furthermore, long term and heavy grazing practices reduce the potential for regeneration of riparian vegetation.

Vegetative Condition

With the exception of the uppermost section of C-1, which is thickly vegetated with mature willows, bank vegetation is absent, or consists of shallow rooted annual vegetation. While some seedlings have developed on bar forms, these are apparently scoured away regularly and not able to establish themselves.

Vegetation on the floodplain consists of sage and rabbit brush, and occasional mature cottonwoods. Cottonwoods occur in clusters and are associated with point bars. Structural diversity is low in that only mature cottonwoods exist, with little to no regeneration. This lack of regeneration is likely due to a combination of factors including grazing practices, water supply, and the inability of seedlings to regenerate due to stream energy in the incised channel.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.

While not necessarily a channel recovery strategy, protection of infrastructure at risk is generally recognized as a first priority in unstable systems. These fall into two categories: 1) those related to threat via channel migration and, 2) threat of flooding. In terms of flooding, these risks are more difficult to identify due to the relative infrequency of the 100-year magnitude flood. In light of the above, the following general recommendations are made:

- Conduct a risk assessment to identify private and public infrastructure at risk.
- Develop river stabilization or stress alleviating schemes for areas where significant private or public infrastructure is threatened by river migration.
- Re-assess the current zoning regulations regarding future development in flood prone areas. Insure this assessment relates to an accurate and current 100-year floodplain delineation.

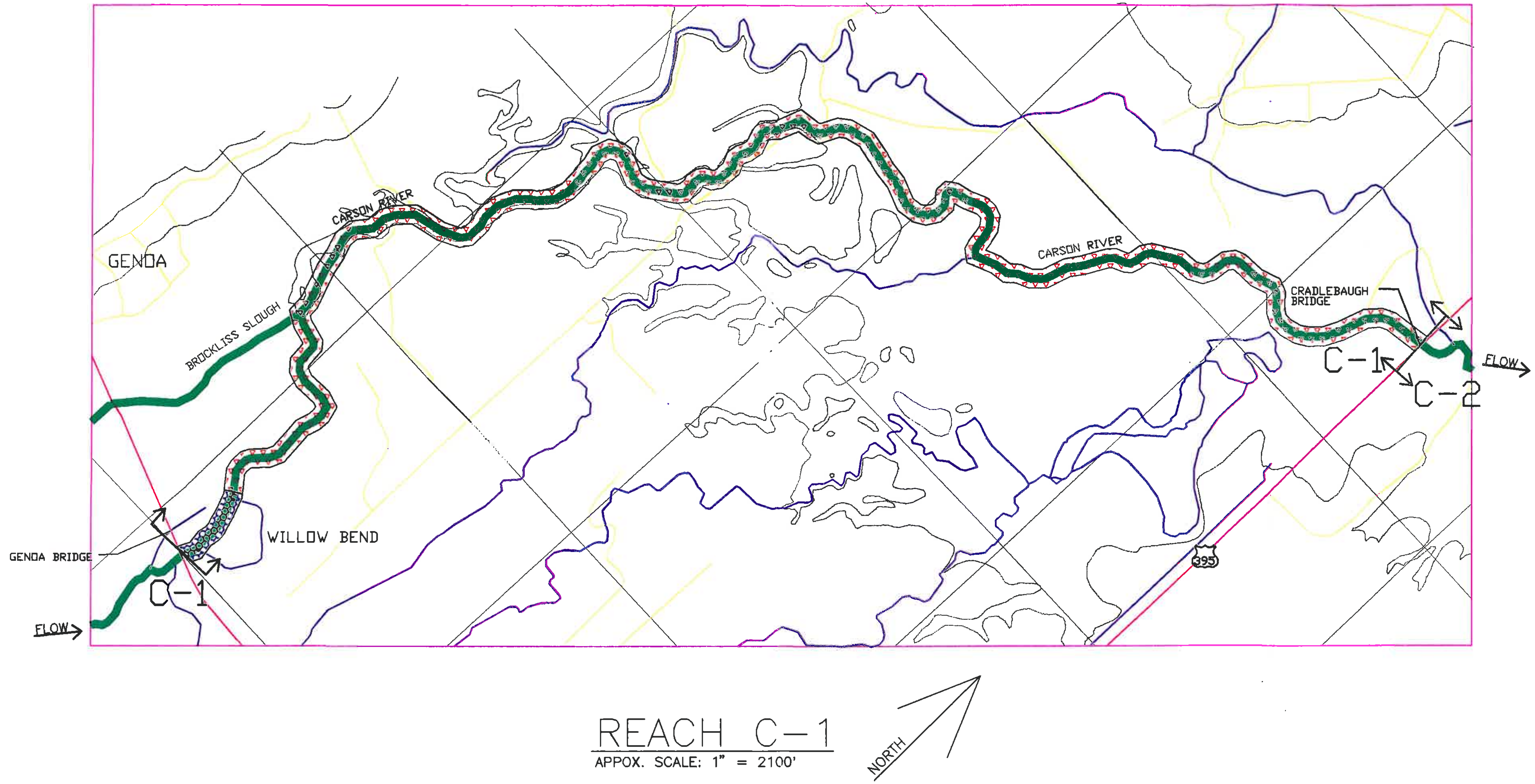
Regarding infrastructure protection, bear in mind that engineered solutions should focus only on at-risk infrastructure at first. Also, as with all river projects, the impacts of the stabilization or floodplain management/development schemes on the hydrologic and geomorphic behavior of the river should be fully analyzed prior to implementation. *All* stabilization schemes should follow the following best practices:

- A complete assessment of the possible effects on upstream and downstream river stability from project implementation.
- Professionally designed and engineered treatments with clearly identified factors of safety and design criteria.
- The use of treatments which will also provide benefits for fish and wildlife.
- Identification of likely failure scenarios and the anticipated costs for long-term maintenance.
- Professionally installed treatments.

To stabilize this reach of the Carson River system, one would need to: 1) consider both lateral and vertical control measures, 2) the influence of a large in-channel sediment supply and the efficient transport of that supply downstream and, 3) the effects of large floods, which the Sierra drainages are very capable of producing. All engineered approaches should adhere to the Basic Design and Engineering Standard Practices for Channel Work described on page 30 or the main text.

- Manage for development of a riparian zone. This should include a grazing exclusion fencing system. Grazing exclusion, however, may not be sufficient in itself to promote riparian zone establishment. Therefore, revegetation should be considered. However, due to steep bank slopes, channel incision, erodable bank materials and poor soil moisture conditions, revegetation efforts would also require bank resloping and supplemental irrigation.

- In the upper section of C-1, where failing banks may threaten residential structures, a more proactive approach to bank stabilization may be required. This area is a prime candidate for bioengineering methods which can provide both a riparian vegetation corridor and adequate bank protection.
- Most bank instability appears to be associated with channel incision. Due to the large scale of these problems and the relatively undeveloped nature of adjacent lands, major channel restoration may not be justified. However, without significant alterations to the channel geometry, bank stabilization may prove difficult.
- Consideration should be given to reconstruction of the existing diversion structure to allow for bedload transport or substitution with pumping galleries. While this may initially increase sediment supply to the lower half of the reach, and thereby exacerbate lateral migration in the short-term, the long-term effect may be aggradation and subsequent reduction of incision problems.
- Genoa Bridge. This bridge appears to be undersized, and given the large in-channel sediment supply upstream, there could be future problems with local aggradation and abutment scour during large floods. All Genoa Lane bridges crossing the Carson and Brockliss are particularly at risk if considering the potential for significant channel shifts above these bridges.
- Cradlebaugh Bridge. Local evidence suggests base level lowering, including the observation of exposed pier footings.



REACH C-1

APPOX. SCALE: 1" = 2100'

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY STABLE
- STABLE
- VERY STABLE

C-2 REACH SUMMARY

SUB-REACHES: S1, S2, S3
LOCATION: Cradlebaugh Bridge to Old McTarnahan Bridge

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: C5c/M/V S2: F5/S/NA S3: F5/E/III

General

Reach C-2 is split into three sub-reaches. S1 is a sinuous, meandering channel for approximately two miles, starting from Cradlebaugh Bridge. This section of channel has exhibited significant channel shifts since the 1938 aerial photographs. While sinuosity and stream length have remained fairly constant, many meander bends have been abandoned or cutoff, while others have been extensions of existing bends in a downstream direction. Channel migration is checked in some locations by prominent willow growth in former meander channels. The channel is incised, with bank heights averaging approximately 10 feet. This reach is located in an area of extensive meander scars, indicating a long history of channel shifts. Sediment supply may be exacerbated by the entrenched state of the channel, and lateral migration rates may in turn be exacerbated by sediment supply. Incision may be related to channelization in S2.

S2 is approximately one mile of straightened channel. 1938 photos show a sinuous channel with well developed meanders. Channelization since this time has resulted in approximately one mile of perfectly straight channel, with a 20 percent reduction in channel length. This reach is relatively stable in that channel banks are well vegetated and show little indication of recent or significant erosion. Lateral bars and mid-channel sand bars have formed throughout this reach, likely a result of sediment supply from upstream bank erosion.

S3 is the lower sub-reach, located on the State Prison property, and is a meandering channel. Review of historic aerial photographs shows that little change has occurred in the planform of this channel. Planform is, however, controlled to some degree by gross topography, in that the channel runs along the edge of the valley, at the toe of a hill slope, for most of this reach. Bar forms are primarily point bars, which are large relative to channel width, and unvegetated. The channel is a very wide and shallow sand bed with numerous mid channel sand bars indicating excessive sediment supply. While channel planform has changed little, channel width has apparently increased significantly, as evidenced by the size of bars and by the instability of all banks throughout this sub-reach.

Channel Capacity

S1: In sub-reach S1, the channel is capable of conveying between the 10- and 25-yr flood events within its banks. In cross section 1, through the axis of a meander bend, a point bar has formed at an elevation which corresponds to the stage of the estimated 2-year peak flow. Cross-section 2, taken across a straight reach, shows formation of a terrace, or lateral bar, at approximately the same stage. This indicates that the channel may be actively building a new floodplain surface within the channel margins at approximately the elevation of a 2-year discharge.

S2: In sub-reach S2, the channel contains between the 5 and 10-year discharge. As in the upstream section, lateral bar forms occur at the elevation which roughly corresponds with the 2-year discharge.

S3: Cross-sections for S3 were surveyed near the bottom of the reach and indicate that the flows access the floodplain at approximately the 5-year discharge. Bar forms in these sections are low relative to the channel and are inundated on an annual basis.

Land Use

Land use in S1 and S3 is limited to grazing lands, with no riparian corridor exclusion. S2 historically was grazing land, but has not been used for many years. Currently, S2 has no apparent land use adjacent to the channel and can be considered as a privately owned natural environment.

Relative Stability

Stable to Unstable

General

Stability ratings in E-2 range from stable in S2 to moderately unstable in S1, to unstable in S3. Surprisingly, the most altered section, S2 which has been channelized, exhibits the greatest stability. This appears to be related to the thick and healthy willow growth on the channel banks and the fact that this area is not grazed or otherwise impacted by land use. S1 is incised and exhibits signs of significant lateral migration, both historically and currently. Incision may be related to the channelization of S2 below. This sub-reach is currently showing signs of recovery following entrenchment as demonstrated by riparian growth on bar forms. However, because the channel contains relatively large flows (5 to 10-year), it is likely that lateral migration and widening will continue for some time. S3, while showing little change in gross planform, is exhibiting many signs of instability, including excessive sediment supply, unstable banks, and an inability to establish riparian vegetation on banks or bars. Channel width may continue to increase for some time due to high bank erodability, rather than due to channel capacity.

Bank Stability

S1: unstable S2: stable S3: unstable

S1 has unstable banks throughout the reach at outside bends and straight sections. Bank heights range from 8 to 12 feet, with most banks being 1:1 or steeper. Bank material composition is sand to silt and banks are being undercut on a regular basis. Grazing impacts are apparent, and may be limiting re-establishment of riparian vegetation in places. Isolated areas of bank stability coincide with well vegetated old meander scars.

S2 banks are stable, 3 to 6 feet in height, range from 1:1 to 3:1 slopes, and are thickly vegetated.

S3 banks are steep and unstable and significantly affected by grazing. Riparian vegetation is nearly nonexistent. Bank heights range from 4 to 7 feet and bank materials are sand and silt. Bank erosion occurs unilaterally along both banks, but is exaggerated at outside bends.

Vegetative Condition

S1: The relative height of the floodplain relative to the channel may be inhibiting riparian vegetation due to reduced moisture. Mature cottonwoods exist on the floodplain, though they are sparse, and old meander bends are thickly vegetated with willows. Many bars show signs of establishing riparian vegetation with sprouts and young willows.

S2: There is a prominent, though narrow, riparian corridor of all age classes of willows. The riparian zone varies from 0 to 100 feet wide. Floodplain condition is good, with 90 percent coverage of grasses and shrubs. Abandoned channels (from channelization) are thickly vegetated with willows and there is some wetland development.

S3: Riparian species are virtually non-existent and floodplain conditions are poor with 30-60 percent bare ground, sparse grasses and shrubs. Grazing impacts are significant. Some willows exist in a parallel slough, though these are heavily impacted by browsing.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

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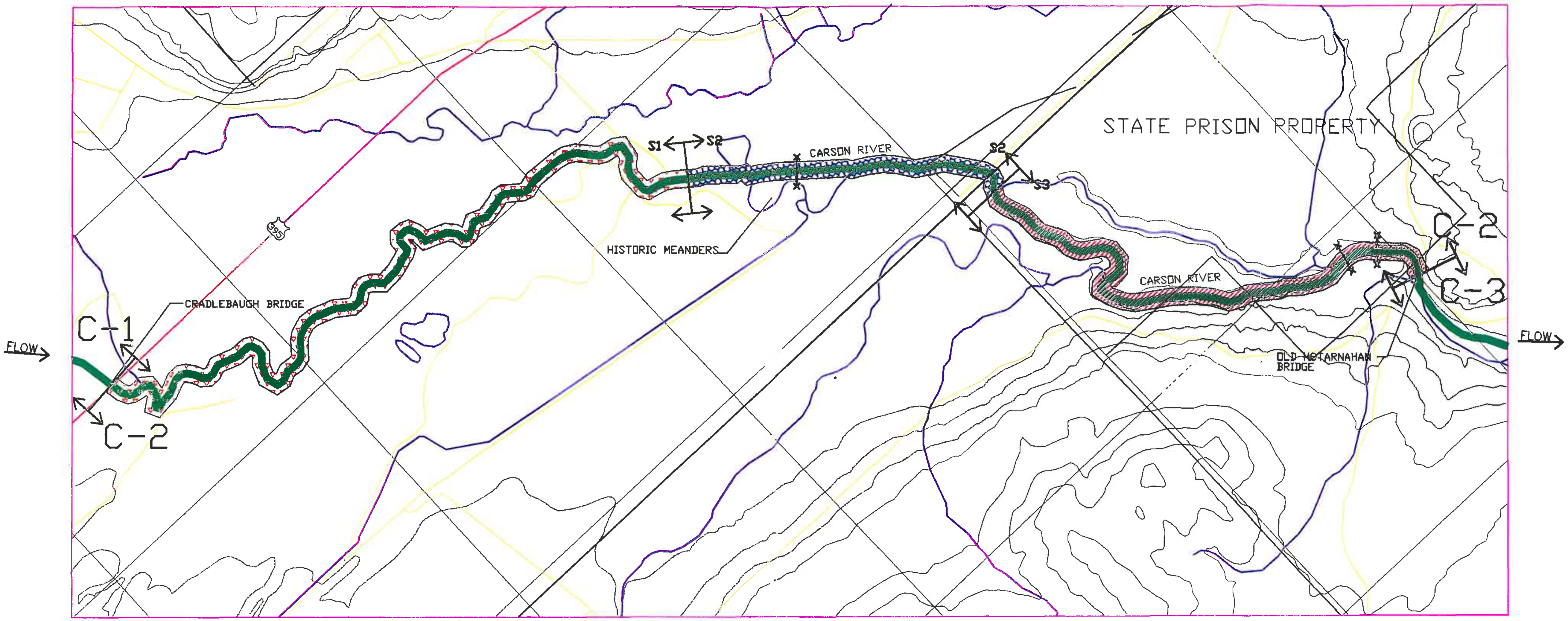
- S1: No management or recovery actions are recommended beyond encouraging development of a riparian corridor, which includes protection of pioneering riparian vegetation on channel bars. This reach is incised. However, it appears to be recovering and adjusting without significant proactive management.
- S2: No management or recovery actions are recommended. Due to the current status of grazing exclusion and essentially no land use, this reach of channel is stable. Recommendations are limited to allowing planform to adopt former channels or increase sinuosity over time.
- S3: Management recommendations for this reach are limited to establishment of a grazing exclusion to allow development of a riparian corridor. This may require revegetation, as volunteer plants and seed sources may be limited.



REACH C-2

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY STABLE
- STABLE
- VERY STABLE

C-3 REACH SUMMARY

SUB-REACHES: S1, S2, S3
LOCATION: Old McTarnahan Bridge Crossing to Deer Run Bridge

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: B5c/M, R/IV.5 S2: na/S,m/V S3: C5c/S,d/NA

General

Reach C-3 is largely a stable reach with only slight instability present in S1. Neither channel straightening or levee work appears to have occurred in recent history. In fact, the 1938 to 1990 aerial photo comparisons show remarkably little change in the position of the channel thalweg. Perhaps more interesting than planform stability is evidence that in 1938, the active channel was much wider than currently and that gravel bars at that time have now become vegetated. In 1937 the fifth largest flow of record, estimated at an approximate 25 plus-year event, passed through the valley. It appears that the current channel has fully recovered from that event.

S1 is characterized by moderately sorted very fine grained sediments, is incised 5 to 10', meandering, and with high flow channels through a relatively well vegetated floodplain. Channel shape ranges from rectangular to irregular. Immediately downstream of S1 is an unclassified narrow valley sub-reach which is large cobble dominated; (no access to this section). At the canyon mouth, the Mexican Dam is the most prominent geomorphic control feature. The fall over the dam is over 10 feet; its backwater extends upstream at least a thousand feet. S2 begins below the Mexican Dam and extends to Lloyds Bridge. This reach is dominated by larger well-sorted substrate; Dmax 16", D50 5", and D25 2" and appears fairly well adjusted to its bedload regime. Channel incision is only moderate; estimated at 2 to 3 feet. Riffle-pool sequences are present though somewhat infrequent in a moderately incised valley bottom with multiple channel threads separated by well vegetated islands. Bar types are dominated by point/transverse and point/mid combinations. Channel shape is generally irregular. In contrast, channel substrate is much finer and moderately sorted in Reach S3, (D50 sand), and the reach is characterized by point/alternate bars. Channel shape is trapezoidal; in plan view it is fairly straight. The S3 channel was not judged to be incised by field observation, though cross-section data indicate incision of up to 5 feet.

Channel Capacity

S1: Cross-sections in S1 indicate that the channel is containing approximately a 5-year flow, with greater flows accessing the floodplain. Bar form elevations roughly correspond with the 1.25-year flow.

S2: No channel slope was measured at this location.

S3: The channel at the cross-section locations in S3 consists of a roughly 7 foot deep, one hundred foot wide area which contains the 5-year flow. The elevation of prominent bar forms corresponds with the stage of the 5-year discharge. Other bar forms exist at elevations well below the annual high flow elevation. The cross-section defined by the elevation of the left bank floodplain contains 25-year or greater flows. These characteristics indicate that the overall channel is containing significant flows on the developed left bank, and may be dissipating high flow energy along the right bank. However, containment of 5-yr and greater flows within the main channel generates significant erosional forces along steep banks.

Land Use

Mixed land use characterizes reach C-3. S1 is historic agricultural/grazing land with some new development in the floodplain. S2's major use appears to be recreation, including ORV's. In S3, a broad mix of grazing and agriculture, golf-course and ruralization development is present.

Relative Stability

S1: Unstable S2: Very stable S3: Stable

General

Reach C-3 was judged to be generally stable. S1 was is moderately unstable due to the presence of a high degree of potential bank instability, though the sub-reach appears to have undergone the most extreme geometry changes in the past, and is now either in as good of condition as is likely given upstream instability or is still recovering from past incision. Note that in the Harvey-Watson incision class, it rates a IV.5, suggesting that it is in an advanced class of recovery. S2 is very stable, with the exception of one high vertical bank area which may be considered a natural feature. S3 is stable with some indication of incision, though the extent of incision to date is not greatly affecting overall stability.

S1's stability is largely due to the fact that the riparian and floodplain condition is generally good relative to the incision. Also, well vegetated high flow channels are present, which helps distribute flood energy, reducing pressure on the otherwise vulnerable main channel banks. In many ways, S1 may represent maximum potential for other reaches with similar entrenchment. Factors aiding this potential include: absence of levees, very low land use pressure and perhaps the grade control capabilities of the very hard canyon sub-reach immediately below.

S2's very stable condition is in part related to the more erosion resistant bed and banks; the former derived from large channel and bank substrate and the latter due to excellent riparian health on channel fringes and some contact with a moderate floodplain area within the entrenched greater channel (H-W class V). Also, levees are absent and land use pressures are low. The influence of the upstream Mexican Dam is difficult to assess, though it is possible that grade control provided by the dam and sediment storage behind it has favorably reduced the load through S2 and S3. Excellent willow vegetation, absence of levees, and low land use pressure also likely account for S3 stability.

Bank Stability

S1: unstable S2: stable S3: moderate

In S1, the average bank is 7 feet high and between 3:1 and 2:1. 40% are 1:1 to vertical, composed of both cohesive and uncohesive homogenous fines. Most bank erosion is occurring at outside bends, with point bar development and willow communities on inside bends. Bank failure is from undercutting and gravitational failure. An estimated 60% of banks are well vegetated. In contrast, except for 150 foot long, 20 foot high vertical bank, S2 banks are 90% stable and vegetated. Erosion, where present, is from undercutting of outside bends. Average bank heights are 5 feet and generally between 1:1 to 3:1, and composed of cohesive fines (vegetation cohesion) and fine gravels to sand. S3 banks are 70% stable and vegetated, average 5 feet high and 80% are 2:1 or flatter. Bank composition is sandy silt with vegetative cohesion. Unlike S1 and S2, approximately 30% of the banks have been altered by rip rap, vegetation clearing, grazing and ORV use.

Vegetative Condition

S1 and S2 have fairly well vegetated floodplains with shrubs and trees well represented. Riparian zone widths range from 10 to 100 feet for both. S3 has a much more narrow riparian width, (maximum to 40 feet) and more of a rangeland condition in the floodplain. Riparian diversity is moderate in S1, high in S2, and moderate in S3. In all three sub-reaches, woody sprouts, young, and mature age classes are common along the channel fringe; most of this growth is willows, though cottonwoods are much more common in S1 and S2.

Channel Recovery And Land Management Recommendations

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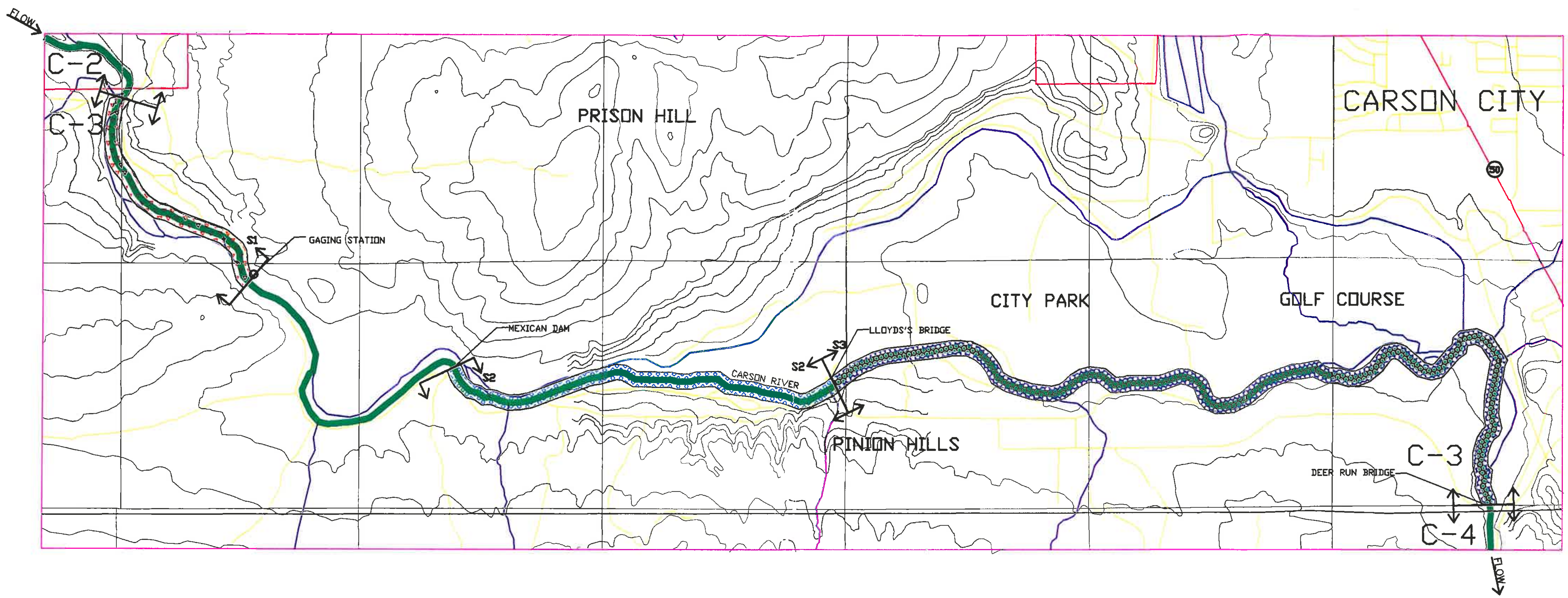
For all sub-reaches, management for increased and or existing riparian and floodplain vegetation is recommended. In S2, it is recommended that public access be better planned to eliminate unnecessary impacts in the floodplain forest and elimination of ORV use in the channel and floodplain. In S3, it is also recommended that ORV use in the channel and floodplain be eliminated and an added emphasis on BMP's which promote further riparian expansion. C-3 does not appear to be in need of any direct action for channel stabilization, as the channel condition is relatively good and non-impacted relative to up- and downstream reaches. This reach may bear further study to assess the reasons for its apparent stability in the midst of up- and downstream reach instability.



REACH C-3

APPOX. SCALE: 1" = 2300'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-4 REACH SUMMARY

SUB-REACHES: N/A
LOCATION: Brunswick Canyon, Deer Run Bridge to Ricci Diversion

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

C-4: B1/S/NA

General

Because of the perceived high stability and low priority of this reach, ground observation of Reach C-4, Brunswick Canyon, was observed from the road along the canyon rim and high up slope. The reach can be generally described as a highly confined, bedrock controlled channel with large substrate. Because of its confinement and minimal land use effects (due to access), little human impacts have affected this section. Furthermore, frequent bedrock controls, natural bed armoring, and rocky banks lend a natural stability that is not easily altered.

Towards the bottom of the canyon, the Dayton Town Diversion exerts heavy influence on channel grade and sediment transport. The diversion is of the gravel push-up type, with an approximate fall of 10 feet over its crest, and backwaters several thousand feet upstream. Since the dam, in one form or another, has been in place for approximately 130 years, the influence on local geomorphology is probably significant and consistent. Though an analysis of the volume of sediment stored behind the dam was beyond this report's scope, it is possible that is significant. Due to the fact that this dam is downstream of the old stamp mills in upper Brunswick Canyon, there is a possibility that it is a sink for mercury used in that milling era.

In its current configuration, the diversion is not capable of withstanding damage and loss during flood events. The impact on downstream sediment supply during dam failures is worthy of consideration, since the potential for stored sediment behind the dam becoming suddenly and massively available is present. However, it should be worth noting that the segment of stream immediately downstream of the dam is in very good condition, with riffle pool sequences and a reasonably identifiable bankfull channel line. The vegetative condition of the site is excellent - perhaps with the largest riparian zone width and highest diversity of any upstream reach.

Channel Capacity

No cross-sections were measured in this reach.

Land Use

Land use in the canyon is limited to isolated camping and recreation areas, with some ORV use. Much of the channel is difficult to access and there is no functional floodplain.

Relative Stability

Very Stable

General

The bedrock control of grade, combined with large substrate sizes and generally good health of the riparian corridor make this an exceptionally stable reach. The one exception to this observation relates to the Dayton Town Diversion (discussed above), whose susceptibility to failure during flood flows makes this segment potentially unstable.

Bank Stability

Channel banks in the canyon consist of large rock and riparian vegetation. Viewed from the road above the canyon, there was no apparent bank instability.

Vegetative Condition

Within the canyon, vegetation consists of all age class cottonwoods, xeric canyon slope species, and areas of riparian growth. Because floodplain and channel bank area is limited due to canyon confinement, there is little room for a riparian corridor. The lack of access to the canyon channel precluded detailed observations of vegetation condition.

As noted above, the vegetative condition of the segment downstream of the Dayton Town Diversion is excellent - perhaps with the largest riparian zone width and highest diversity of any upstream reach. Maximum riparian widths approach 100 feet, with abundant evidence of willow and some cottonwood regeneration with moderate to high diversity.

Channel Recovery And Land Management Recommendations

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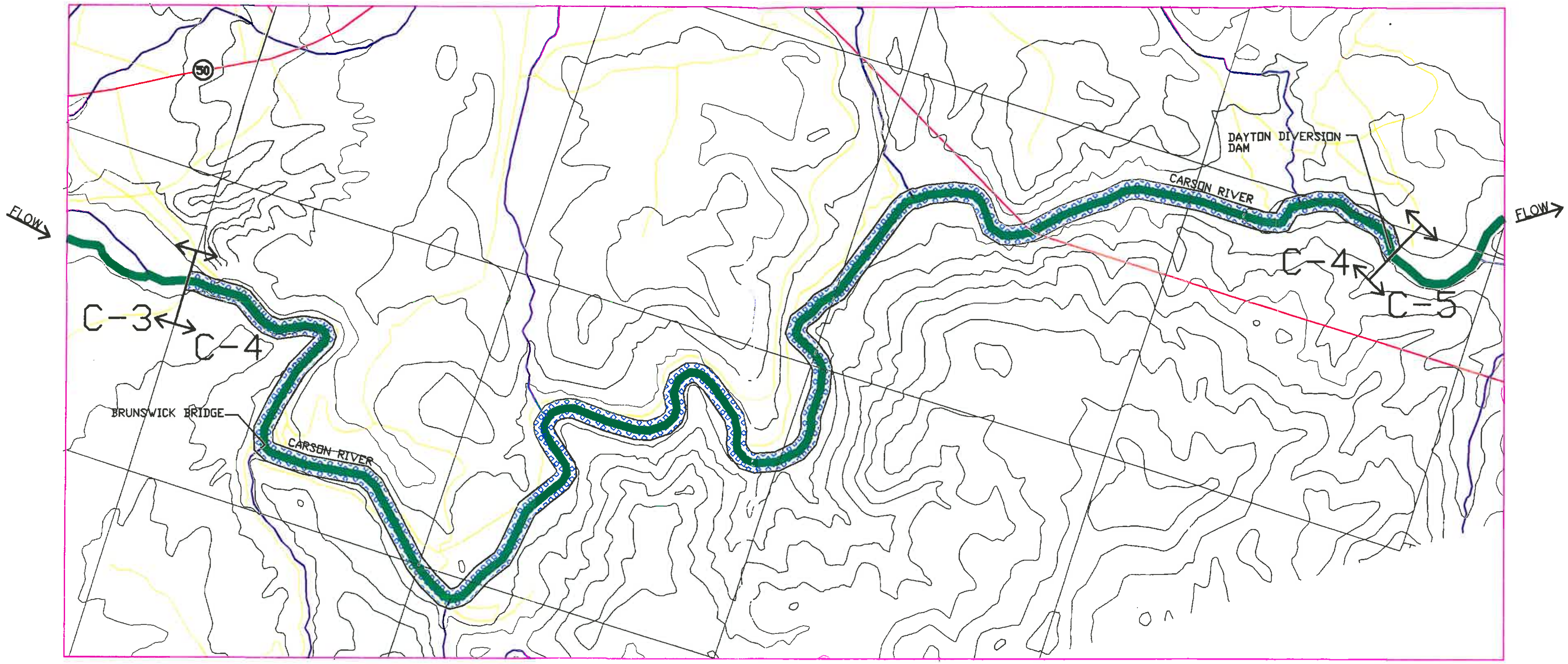
Better control of recreational activities in the canyon may be warranted, though overall, the existing impacts are not severe. It is recommended that the canyon be managed as a recreational corridor given its natural scenic beauty and historical connections with the Comstock mining period.

There is local interest in building a dam in the canyon to "control downstream flooding" and recreation. While we can make no recommendation relative to the cost effectiveness of this strategy, we believe that no dam should be constructed without also considering the impacts on downstream channel stability. While it is true that large floods cause changes to downstream channel geometry, there is also ample discussion in the literature as to often unwanted channel changes *because* of upstream dams (USGS, 1996). These potentially conflicting effects of dams would need resolution.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.



REACH C-4

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-5 REACH SUMMARY

SUB-REACHES: S1, S2
LOCATION: Ricci Diversion to Dayton Bridge

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: B4c/R,m/V S2: F4/M/IV

General

This reach begins at the mouth of Brunswick Canyon and was leveed in some areas in 1964. The channel is incised relative to the historic floodplain. In S1, the depth of incision is not as pronounced as some up- and downstream reaches. Relative to incision, the channel is in late stages of evolution and is recovering, though both subsections are now exhibiting meandering characteristics and at points eroding outside bends and levee toes. Channel shape is irregular in S1 and trapezoidal in S2. Both sections show well sorted bar forms, ranging from point/transverse and point/alternate in S1 to the emergence of some mid-channel bars in S2, which with other indicators, suggest some aggradation. S1 bar forms are well armored and appear to have been laid down during a very large flood. Fine sediment deposition in association with these features has promoted a well vegetated riparian fringe in S1. Channel substrate ranges from large cobble to fines (Dmax 12", D50 5") in S1 to slightly finer material in S2. The S1 bedforms result in weakly developed pool-riffle sequences; by S2 the aggradational characteristics have overridden this development.

The Ricci diversion, at the top of S1, is undoubtedly having some influence on downstream dynamics. Like the Dayton Town diversion, it is of the gravel push-up variety, and prone to failure during moderate floods. Failure during floods and the resulting sediment pulse through C-5 may be responsible for some of the instability noted in S2. In addition to this diversion, another diversion near the Sbragia ranch is present. Another gravel push-up type, in its current configuration it may pose some tangible flooding and erosion problems for the home owner on the immediate left bank. During our inventory, the crest of the diversion was near the elevation of the left bank. In a worst case scenario, flood water surfaces will be elevated to the point of overbank flooding. An alternative scenario is that the diversion will fail during a flood, reducing flood risks, though its failure may impact the already eroded left banks adjacent to the home and downstream stability due to sediment pulsing. It is strongly recommended that this diversion structure be replaced with attention to the design criteria and considerations provided in this report.

Channel Capacity

S1: The elevation of the right bank floodplain at this cross-section roughly corresponds with the 5-year discharge. The elevation of a bar form on the left bank with young cottonwoods and willows corresponds with the stage of the 2-year discharge. The bank on the left bank contains flows between 25- and 50-year discharges.

S2: Hydraulic analysis of the cross-section in this sub-reach was not possible because channel slopes were not surveyed.

Land Use

Land use is a combination of grazing, agriculture, and some housing in the floodplain. Housing, fencing, and outbuildings range from 20 to 100 feet from the bank toes.

Relative Stability

S1: Stable S2: Moderately Unstable

General

In S1, stability is fairly good as the 1963 levees were set fairly well back and the river has had some freedom to meander. In fact, the river has begun to rebuild a floodplain surface where channel energy is diffused during floods. The Downs class of R,m suggests a recovering channel with incipient meandering, while the HW incision class of IV suggests a channel adjusted to its new base level. Lateral and side bars are well vegetated, enhancing stability. The cobble dominated bed has prevented deep incision. In contrast, S2 is showing more active meandering characteristics, which may be in response to aggradation in this section, perhaps due to a flatter bed slope and sediment pulsing from diversion failures in S1. Instability on outside bends may be of concern, since the left bank floodplain is fairly densely developed. Furthermore, the low width:depth ratio evidenced in the cross-section indicates that river stage rises more rapidly than in a more natural cross-section and thereby increases erosional forces along the banks.

Bank Stability

S1: moderately stable   S2: moderately stable

S1 banks are mostly stable, though several outside bends have rip rap on the bank toes. Bank heights range from 2 to 10 feet, with 10 feet being the levee top, where levees exist. Failure of banks is from undercutting; 90% of banks are 2:1 or flatter and well vegetated. Bank composition is un-cohesive heterogeneous cobble to small gravels. In contrast, more active meandering has destabilized bank toes in several areas of S2; bank heights range from 4 to 10 feet and average 7 feet. About 50% of the banks are 2:1 to vertical and composed of uncohesive small gravels and fines; most of these banks are unvegetated. Some bank protection efforts observed are in poor shape and consist of concrete rubble and rip rap.

Vegetative Condition

Inside Levee: Inside the levees, where they exist, 1 to 10 year old cottonwoods and willows are common along with non-native perennial grasses. Structural diversity is moderate, reflecting the absence of mature cottonwoods. In S1 riparian widths range from 10 to 50 feet, averaging 30 feet. Downstream in S2, bank vegetation thins considerably, with average widths of 15 feet, and is more confined to channel fringes. Large depositional bars are mostly unvegetated.

Outside Levees: Outside the levees, where they exist, grasses are dominant with scattered mature cottonwoods. A land owner in S1 suggests that the recent elimination of grazing pressure has resulted in excellent growth of woody species.

S1: Riparian cattle grazing should be discouraged until the riparian community has reached full potential. Consideration should be given to removing any right bank levees as very little development is present in the historic floodplain. Such a plan would perhaps accelerate the recovery of this reach to a yet more stable environment. Where bank toes on the developed left bank levees are being eroded, it is recommended that well engineered rip rap be installed at the levee toes to prevent further undercutting. Such a program should coincide with extensive vegetative planting through installed rip rap and on the upper slopes.

S2: Like S1, riparian cattle grazing in this reach should be discouraged; it is in worse vegetative shape than S2. Managing S2 for riparian recovery should be a priority. Levee failure is ongoing where they have not been maintained in a professional manner and/or recent rip rapping is poorly accomplished. It is recommended that well engineered and installed rip rap levee toes be installed in combination with heavy re-planting. The Holly diversion dam represents a major potential problem as described above, and should be dealt with (removed) soon. More careful analysis of this diversion point is warranted such that waters can be diverted without potentially increasing flooding risks and bank erosion adjacent to it. The home owner on the left bank should actively investigate and pursue bank stabilization along their property, as the home is very close to the active channel and could conceivably be threatened during a moderate magnitude flood.

Downstream, the Sbragia property is slated for some channel stabilization activity on the left bank. The river channel dynamics in this location appear to warrant careful engineering, particularly since the bank erosion is part of a larger channel meandering and deposition process. Any spot fix must be very rigorous to inhibit further channel migration. Further, the failure of the Holly diversion dam upstream appears imminent during even a small flood. The large pulse of sediment which may then need to be transported past the Sbragia property should be considered in any design to enhance the site's stability. Currently, a large depositional bar is forcing flows towards Sbragia's bank; a flood event which adds to this bar will increase the pressure on that bank. Therefore, a hydraulic analysis of existing and proposed conditions should be considered essential, and is typical of standard engineering practice in these environments.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.

Much of C-6 is in relatively undeveloped area and may therefore be a good candidate area for strategic bank stabilization and channel geometry reconfigurations. However, total recovery of C-6 would still be a major undertaking due to: some severe channel instability, mixed land ownership, and geomorphic activity suggesting a channel in a long-term transition state.

Lower intensity approaches include selective bank stabilization and construction of high flow terraces and floodplains in the upper subreaches. Subreaches lower down on C-6 have potentially gained adequate flood prone width though still have very actively eroding banks. Strategies to stabilize selected banks and the enhancement of flood prone area could also prove feasible here. Detailed opportunities should be investigated with a feasibility assessment.

While not necessarily a channel recovery strategy, protection of infrastructure at risk is generally recognized as a first priority in unstable systems. These fall into two categories: 1) those related to threat via channel migration and, 2) threat of flooding. In terms of flooding, these risks are more difficult to identify due to the relative infrequency of the 100-year magnitude flood. In light of the above, the following general recommendations are made:

- Conduct a risk assessment to identify private and public infrastructure at risk.
- Develop river stabilization or stress alleviating schemes for areas where significant private or public infrastructure is threatened by river migration.
- Re-assess the current zoning regulations regarding future development in flood prone areas. Insure this assessment relates to an accurate and current 100-year floodplain delineation.

Regarding infrastructure protection, bear in mind that engineered solutions should focus only on at-risk infrastructure at first. Also, as with all river projects, the impacts of the stabilization or floodplain management/development schemes on the hydrologic and geomorphic behavior of the river should be fully analyzed prior to implementation. *All* stabilization schemes should follow the following best practices:

- A complete assessment of the possible effects on upstream and downstream river stability from project implementation.
- Professionally designed and engineered treatments with clearly identified factors of safety and design criteria.
- The use of treatments which will also provide benefits for fish and wildlife.
- Identification of likely failure scenarios and the anticipated costs for long-term maintenance.
- Professionally installed treatments.

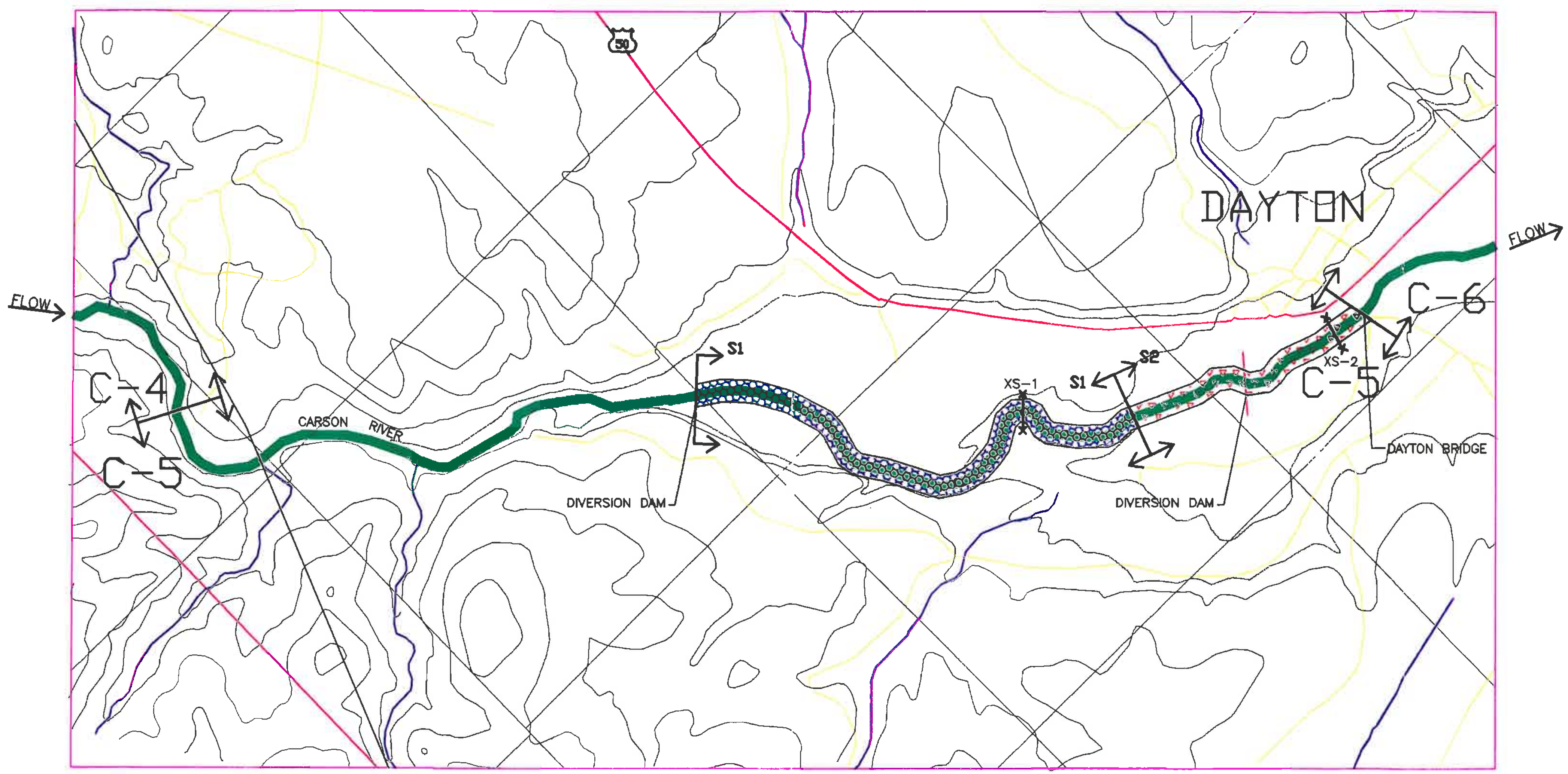
To stabilize this reach of the Carson River system, one would need to: 1) consider both lateral and vertical control measures, 2) the influence of a large in-channel sediment supply and the efficient transport of that supply downstream and, 3) the effects of large floods, which the Sierra drainages are very capable of producing. All engineered approaches should adhere to the

Basic Design and Engineering Standard Practices for Channel Work described on page 30 or the main text.

- Active programs to remove aggraded gravel may have negative effects on existing channel-side vegetation. Any proposal of this nature should be rigorously scrutinized.
- Erosion protection on outside bends may be warranted should infrastructure become threatened following future flood events. Protection schemes should consider:

  1. Professionally designed and installed treatments including rock terrace bank toes in combination with bioengineered banks and bendway weirs.
  2. Strategies to stabilize levee toes with well installed riprap; perhaps in conjunction with the construction of a low terrace (similar to that found in stable reaches) and/or rock flow deflectors and an aggressive planting program on treated banks. Deflectors may be necessary to provide protection to the Burnell ditch, as it is vulnerable to capture by the river directly below the current diversion point.
  3. The construction of a terrace on both banks in conjunction with hidden rip rap protection on bank and/or terrace toes and extensive revegetation. The low-flow water elevations, well below even the midbank region, may stymie all but the most elaborate revegetation attempts.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.



REACH C-5

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-6 REACH SUMMARY

SUB-REACHES: S1, S2, S3, S4, S5, S6
LOCATION: Dayton Bridge to Quilici/Minor Property

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: C4c/R,m/V	S2: C4c/M,R/IV or V	S3: na/C, braided/V
S4: C5c/E/III	S5: C5c/R,m/V	S6: F4/U/III

General

The geomorphic character of this reach is diverse, as evidenced by the six distinct subsections identified in the field. On one end of the spectrum, S1 is stable and well armored while by S6 the channel is fine grained and extremely unstable laterally. Sections of both banks of C-6 were leveed during 1964 and many sections were straightened, eliminating well defined and tight meanders with large amplitudes (according to adjacent land owners). Many levee sections are completely gone while others are failing. Comparisons of aerial photos between 1980 and 1990 indicate that the channel was very active in that period. In particular, the active channel has widened considerably in S3, S4, and S6. Apparently, the braiding characteristics noted in the field in S3 are as recent as 1980; the aerial photos of that time show a much narrower, mostly single thread channel. This evidence of recent channel change is also supported by the apparent age of the woody vegetation growing on the bars in S3. The middle segment of S4 also widened dramatically and deformed its meander pattern significantly (one meander inverted between 1980 and 1990). Channel width remained similar in S5 between 1980 and 1990. The "blow-out" on the Minor property (S6) also appears to have been initiated between 1980 and 1990, with most damage occurring in 1995. Field and land owner observation suggests that this increase in active channel width is still occurring.

In the downstream direction, bed particle sizes decrease dramatically from a Dmax of 12" in S1 to 2" in S6. This appears to be loosely related to the transport versus aggradational characteristics of the reach in a downstream direction. For example, S1, with larger cobble, appears to be effectively transporting delivered sediment downstream, while from S3 down, mostly consistent expression of many mid-channel and alternate bars are associated with finer substrates. Of these sub-reaches, S3 and S6 appear the most aggradational; S3 is braided and S6 has many heavily dissected mid-channel bars. S1 is characterized by well armored point/transverse and point/alternate bar combinations resulting in some pool-riffle sequences.

Relative to incision and channel state, S1, S2, S3, and S5 appear to be in similar incision classes whereby the channel is now adjusting laterally within a wide active channel corridor defined by fairly well established sediment benches (incipient floodplain surfaces) which display varying degrees of vegetation. Estimated incision relative to the old floodplain ranges from 2 to 3 feet in S1 to 1 to 2 feet in S5. In contrast, S4 and the upper parts of S6 are fairly rectangular incised channels which have not yet developed incipient floodplain surfaces within the active channel. If they "evolve" into more similar channel types both up- and downstream, they may first undergo some active channel widening followed by a period of meandering. In both sub-reaches, this may be beginning as the rate of bank erosion is high and general channel stability is low.

Channel Capacity

S1: The elevation of the cobble mid-channel bar in S1 roughly coincides with the stage of the 5-year flow discharge. The elevation of the top of bank on the right bank is between the 5- and 10-year stages. 10-year flows are contained within the channel. The left bank, however, probably is not breached until roughly the 25-year event. It appears that the cobble mid-channel bar may have been deposited during a moderate level event (5-yr). No other correlations are revealed with respect to more frequent flows and channel geometry.

S2: The channel at this cross-section is apparently breached on the left bank at less than 10-year flows, while the bank on the right bank contains greater than 25-year flows. A bar form exists on the right bank, the elevation of which corresponds with the stage of a 2-year event.

S3: No cross-section or hydraulic analysis is available for S3.

S4: As in S1, the elevation of a bar form on the left bank is equivalent to the stage of a 5-year flow. The gravel and cobble deposits along the right bank correspond to the elevation of a 10-year flow event. No other relationships between geometry and flow events is apparent. Both banks of the channel contain the 25-year event. The left bank elevation is roughly equivalent to the stage of that event, while the right bank may contain greater flows.

S5: Despite that levees were not constructed or are gone from this section, the channel at this cross-section contains roughly the 25-year flow at both banks. A significant bar form exists along the right bank. A prominent break in slope of this bar corresponds with the stage of a 2-year flow. The top elevation of this bar, however, is at the 10-year stage.

S6: This channel cross-section contains flows between the 25- and 50- year discharges on the left bank, and greater than 50-year flows on the right bank.

A 200 foot wide bar or terrace along the left bank appears to be inundated on an annual basis.

Land Use

Land use varies throughout C-6: S1 is characterized by floodplain development on the left bank and agricultural use on the right; S2 includes the State Park campground and agricultural uses; S3, S4 and S6 grazing and agriculture; S5 grazing, agriculture and some residences. Infrastructure includes housing, fencing, irrigation ditches, and power poles.

Relative Stability

S1: Stable S2: Moderately Unstable S3: Unstable
S4: Unstable S5: Moderately Unstable S6: Extremely Unstable

General

- **S1:** In S1, stability is fairly good as the 1964 levees are intact and set fairly well back from the active channel. Bars are well vegetated and the riparian fringe vegetation thick. However, upstream instability may contribute to unpredictable channel responses.
- **S2:** Bank erosion on the left bank of S2 is significant and is threatening to capture the Cardelli ditch. This instability is related to mild aggradation and resultant channel meandering. Large and unvegetated bars are present.
- **S3:** S3 instability relates to extensive aggradation within a wide channel with well vegetated mid-channel bars. This reach is moderately braided and appears to switch channels frequently. Wherever these channel threads contact either a remnant levee or abandoned floodplain, significant bank erosion is present.
- **S4:** S4 instability is related to bank erosion, where 60% of banks are unstable. The channel appears to be enlarging in this reach; it has already removed any confining levees on both banks, and is now undermining the abandoned floodplain forest. Given upstream aggradation, this reach appears to be transporting supplied sediment efficiently though the channel may be in transition to a wider and more aggradational type.
- **S5:** S5 is only moderately unstable; instability is related mostly to outside bend erosion and very large point bars composed of easily transported material. Vegetation does not appear able to gain a foothold on the bar surfaces, perhaps due to dewatering during the growing season. Virtually all traces of any levees that may have been constructed in S5 are absent having been long ago eroded away by lateral migration.

- S6: S6 is very unstable and is rapidly increasing its active channel width, up to 60 feet in two years at one point, as identified a landowner. Channel widening is likely caused by significant channel aggradation in conjunction with erosion prone banks.

Bank Stability

S1: stable to moderately unstable S2: stable S3: unstable
S4: unstable S5: moderately unstable S6: extremely unstable

- S1 banks are 90% stable and well vegetated.
- S2 banks are 50% unstable and unvegetated, average 4 feet high, range between 3 and 8 feet, and approach vertical on outside bends. Inside bends are stable. Both S1 and S2 banks are largely cobble to small gravel.
- In S3, remnant levees typically show erosion of the cobble toes; where levees are absent, erosion is high in finer grained historic floodplain soils. Average bank heights are 5 feet and 2:1 or steeper.
- Bank erosion in straight sections is common in S4, as well as on alternate banks in response to flow deflection off of developing alternate bars. Exceptions to levee erosion in S4 include areas of recent work (last 10 years) on levees. 70% of the banks are 1:1 to vertical with fine, uncohesive, heterogeneous soils.
- Bank instability is moderate in S5 and mostly associated with outside bends. Banks average 3 feet in height and are generally 3:1 or flatter.
- Both undercutting and gravitational failures affect S6 banks, with 90% in a failing condition. Outside banks are vertical and composed of very easily eroded sands and small gravel, while inside banks are less steep.

Vegetative Condition

- S1 is characterized by a well vegetated channel fringe with good representation of reproducing woody species (1 to 8 years age) and an absence of mature cottonwoods. Age of growth may relate to recent drought period when channel scour was less severe.
- S2 vegetation is generally sparse on outside bends and generally compared to S1 (sprouts and young woody vegetation is sparse). Mid-channel bars have vegetation in the 0-2 year age range.
- S3 riparian vegetation is sometimes thick on mid-channel bars, with riparian widths between 5 and 100 feet. More reproduction of willows and cottonwoods was noted in this sub-reach than virtually every other Carson River reach.
- In contrast, S4 channel energy seems severe enough that virtually no riparian vegetation is found in the active channel; most vegetation is

confined to the old floodplain and is dominated by old cottonwoods with an understory of more xeric species.

- S5 is characterized by sparsely vegetated point bars on the floodplain fringe, and is youthful where present. Cottonwoods are not reproducing; riparian widths range from 0 to 60 feet. Riparian vegetation is again very sparse, with only isolated patches of youthful willow and cottonwoods usually associated with a low terrace elevation.
- The right bank of S6 is dominated by xeric species. Bars are almost totally unvegetated.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.

While not necessarily a channel recovery strategy, protection of infrastructure at risk is generally recognized as a first priority in unstable systems. These fall into two categories: 1) those related to threat via channel migration and, 2) threat of flooding. In terms of flooding, these risks are more difficult to identify due to the relative infrequency of the 100-year magnitude flood. In light of the above, the following general recommendations are made:

- Conduct a risk assessment to identify private and public infrastructure at risk.
- Develop river stabilization or stress alleviating schemes for areas where significant private or public infrastructure is threatened by river migration.
- Re-assess the current zoning regulations regarding future development in flood prone areas. Insure this assessment relates to an accurate and current 100-year floodplain delineation.

Regarding infrastructure protection, bear in mind that engineered solutions should focus only on at-risk infrastructure at first. Also, as with all river projects, the impacts of the stabilization or floodplain management/development schemes on the hydrologic and geomorphic behavior of the river should be fully analyzed prior to implementation. *All* stabilization schemes should follow the following best practices:

- A complete assessment of the possible effects on upstream and downstream river stability from project implementation.
- Professionally designed and engineered treatments with clearly identified factors of safety and design criteria.
- The use of treatments which will also provide benefits for fish and wildlife.
- Identification of likely failure scenarios and the anticipated costs for long-term maintenance.
- Professionally installed treatments.

To stabilize this reach of the Carson River system, one would need to: 1) consider both lateral and vertical control measures, 2) the influence of a large in-channel sediment supply and the efficient transport of that supply downstream and, 3) the effects of large floods, which the Sierra drainages are very capable of producing. All engineered approaches should adhere to the Basic Design and Engineering Standard Practices for Channel Work described on page 30 or the main text.

- Active programs to remove aggraded gravel may have negative effects on existing channel-side vegetation. Any proposal of this nature should be rigorously scrutinized.
- Erosion protection on outside bends may be warranted should infrastructure become threatened following future flood events. Protection schemes should consider:

  1. Professionally designed and installed treatments including rock terrace bank toes in combination with bioengineered banks and bendway weirs.
  2. Strategies to stabilize levee toes with well installed riprap; perhaps in conjunction with the construction of a low terrace (similar to that found in stable reaches) and/or rock flow deflectors and an aggressive planting program on treated banks. Deflectors may be necessary to provide protection to the Burnell ditch, as it is vulnerable to capture by the river directly below the current diversion point.
  3. The construction of a terrace on both banks in conjunction with hidden rip rap protection on bank and/or terrace toes and extensive revegetation. The low-flow water elevations, well below even the

midbank region, may stymie all but the most elaborate revegetation attempts.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.

S1: From the Dayton Bridge to the Cardelli diversion, the channel is generally stable. The trailer park on the left bank above the diversion may be threatened should the river's flow erode the already inadequate bank protection adjacent to the structures. It is recommended that the banks adjacent to the trailer park be subjected to further investigation and assessed for existing stability. Also, it may be appropriate to move the Cardelli diversion downstream such that capture by the river is less likely. On the right bank, a diversion ditch may be vulnerable to capture should the banks fail. Currently, the rate of bank retreat here is only minor.

S2: In order of priority, three issues need to be addressed: 1) the Cardelli ditch is threatened by continued lateral migration of the river into the left bank in the State Park, particularly at the head of the diversion; 2) the Quilici diversion on the right bank needs improvement such that annual heavy equipment into the section becomes less necessary and; 3) State Park recreational facilities are too close to the river and could be threatened by further channel migration.

To protect the Cardelli ditch and State Park facilities, the left bank needs substantial protection. There are several methods available to protect the bank including: a) rip rap banks, b) install bendway weirs and, c) construct a low terrace with a hardened face adjacent to the failing banks; plant terrace; lay-back or fill vertical banks to angles amenable for revegetation. In conjunction with these options, it is conceivable that the main channel alignment can be moved off the vulnerable left bank. Additionally, total or partial removal of the right bank levee should be considered so that larger flood flows have the opportunity to spread out more (note that the Quilici ditch on the right bank moves away from the river soon after the diversion, and therefore, there would still be a buffer between the river and the ditch). We recommend that a strategy be pursued which is complimentary to the recreational use of the area; in other words, a great deal of thought should be given to design and installation of bioengineered surfaces that will have aesthetic value. Any of the implemented options should be professionally designed and consider the existing and proposed hydraulics of the site. A band aid approach will not likely be cost effective in the long term nor meet the recreational use objectives for the site.

The Quilici diversion is not currently a major problem because the fall over the gravel diversion structure is 2 feet or less. However, as has been noted on other upstream river segments, a much higher push-up diversion structure can have significant impacts on both upstream and downstream stability. It is conceivable that this diversion will need to be higher should the bed degrade at the diversion point. Therefore, consideration should be given to upgrading the diversion point for greater long-term stability and preservation of the current bed elevation. While it is premature to recommend a specific technique to do so, a low rock weir, properly designed and installed, may be appropriate. Clearly, work on the left bank adjacent to the Cardelli ditch, especially if channel re-alignment is considered, would have to be coordinated with protection of the Quilici diversion.

Regarding the State Park facilities, little can be done short of protecting the left bank or moving the facilities away from the river. Options which will protect the Cardelli ditch will also benefit the park.

S3: For the segment of S3 from the end of S2 to the Quilici Ranch, short of managing for instream and bank vegetation, little is recommended from a structural perspective. While bank erosion is high, the channel is also fairly well adjusted in width; in other words, it is unlikely that the river will continue to dramatically widen its active channel, making bank stabilization a low priority. Further, there is no infrastructure threatened by river channel changes. Natural recovery of a functional floodplain appears to be taking place, as evidenced by the youthful willows and cottonwoods on most channel bars. One could conjecture that a multiple channel environment, with well vegetated bars, represents the existing potential for the river today. Other reaches up- and downstream do not show similar development of in-channel vegetation which is key to stabilizing the in-channel sediment load, which is generally high throughout. It is unclear as to why this subsection's vegetative response is so much higher than other degraded reaches, but may be tied to water availability during low flow summer periods which promotes annual growth or to channel hydraulics which define scour of bars.

The failing bank on the right bank of the Quilici ranch is a point of concern for the owner and the Middle Carson management group. After two separate visits to the site, the following observations are made:

- It is unclear as to the need for bank protection given the river's natural tendency toward greater channel width in this area, and given that no infrastructure is threatened. It is acknowledged that the mature cottonwood forest on the old floodplain is threatened by continued migration. However, this forest is not naturally regenerating at this elevation and has an understory of xeric species.

- Any effort to protect the failing right bank downstream should be weighed against the possibility of promoting erosion on the opposite left bank, which is in the process of developing a stable terrace with a riparian fringe. Arresting erosion on the right bank may well accelerate erosion on the downstream left bank; a decision should be made as to the relative value of the land being protected on either bank. There is very clear evidence, just upstream, that the current channel width at the Qulici bank project site is much narrower than can be accommodated by the river.
- Should stabilization occur on this site, recommendations made for S2 bank stabilization should be considered. A tentative effort will not prove to be long lasting as many powerful channel forces are leading to migration into this bank. It is instructive to note that any previous levees downstream of this area have been totally removed by the river; the trend of the river is not to accept efforts to halt migration. Downstream in S3, recent bank stabilization work has taken place which is proving successful to date. While the new bank work has proven to be somewhat effective, it is not clear that applying the same strategy upstream will have the same results, nor is there any guarantee that the new bank work will withstand the test of time and more floods.

Our recommendation is that the river be allowed to migrate as needed in this corridor. We understand that this concept may not be popular with the land owners, but our professional assessment suggests that the river's instability both up- and downstream of the site makes any effort to control the rivers migration somewhat experimental and unlikely to succeed in the long run. Should a "let leave" strategy be adopted, consideration may be given to enhancing the regeneration of woody riparian species on deposited terraces and bars. In this way, the recovery of a new floodplain, at an elevation more conducive for natural regeneration (lower) may be promoted. Enhancement would likely include supplemental irrigation of bar surfaces, as growth after seed set appears to be inhibited by lack of instream flows during the critical summer months growing period.

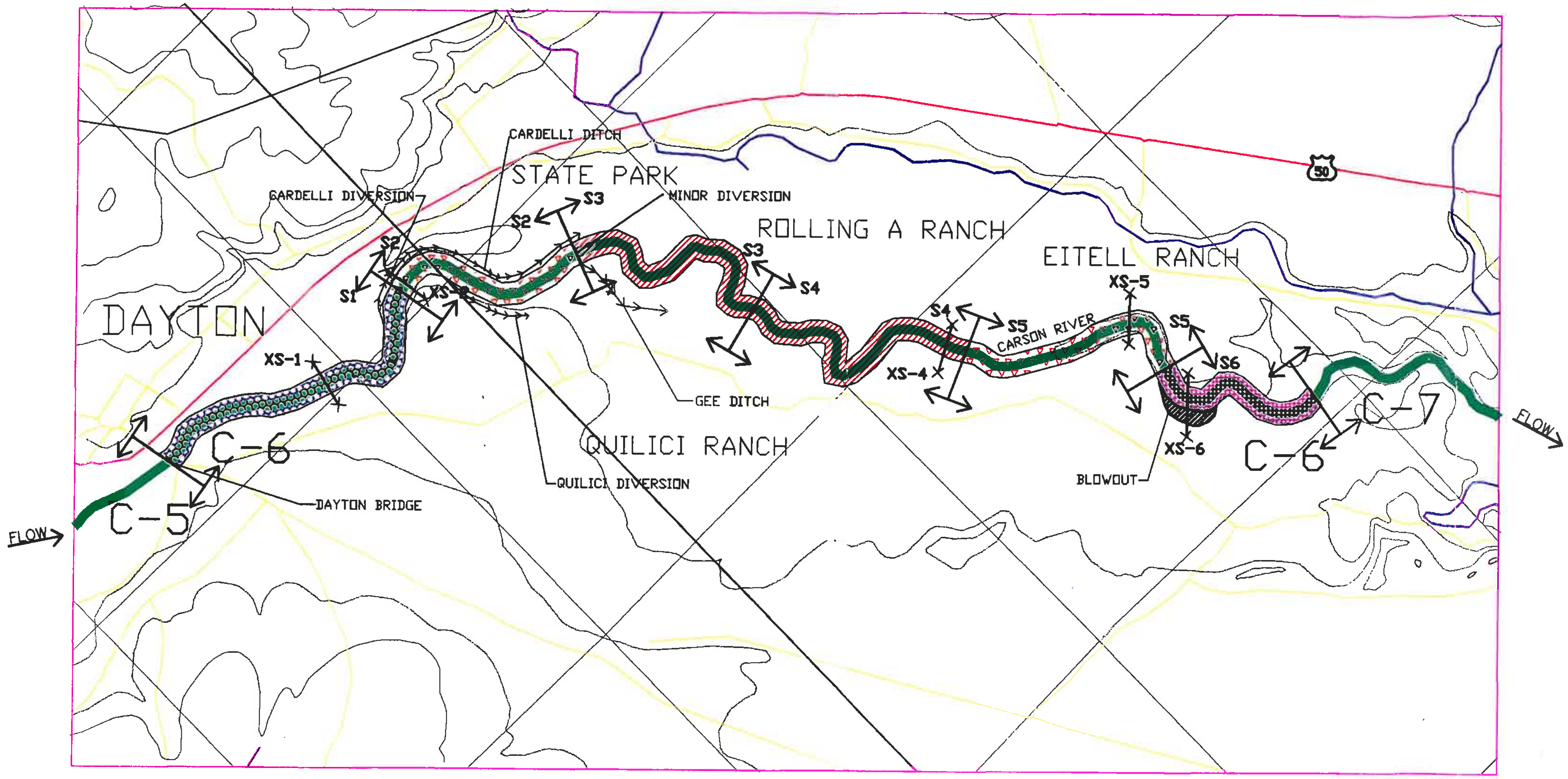
S4: Land owners have described a much different channel prior to channel work than is now present. It is our assumption that the combination of localized channelization and resultant levees confined the river to such an extent that the subsequent flood hydraulics caused all the levees (channelization spoil piles) were removed by the river. Relative to the valley grade, the active channel is too straight. Indeed, the historic river was tightly meandering, narrow and deep, and flooded overbank regularly. Given the current enlarging of the channel through S4, it does not appear feasible to contain the river in a straight corridor. It is our recommendation that the river be allowed to migrate in this reach, and that the overbank and newly forming banks and terraces be managed for woody vegetation.

S5: The river through this sub-reach is much more sinuous than in S4, and may be an analog for the future S4 reach. This statement is qualified by the fact that this section of river has been continuously manipulated by the left bank land owner (Eitel) for many years. The Eitel ranch efforts have been largely to inhibit channel migration towards the ranch headquarters and downstream agricultural ground. The results of these efforts have been partially effective, though the current condition of the improvements is poor as a result of recent flooding. In particular, the river is getting behind the gravel berm (loosely constructed levee) near the ranch headquarters, making the bank behind it susceptible to future erosion. This could jeopardize the ranch headquarters infrastructure if unchecked. Further, observation suggests that the headquarters is vulnerable to flooding in the existing condition. Consideration may be given to building a set back levee around the headquarters to provide protection from large flood events. Downstream, the rock jetty installed to inhibit erosion into the farmed fields is ineffective and actually encouraging erosion of the left bank. While there is a good argument to reduce flood hazards for the ranch headquarters, the cost/benefit of stabilizing the bank adjacent to the farmed fields should be evaluated. Like other reaches, any engineering of a bank revetment should consider the larger forces of the river encouraging migration in this direction.

Additional recommendations for S5 are as follows:

- Consider allowing channel migration below the ranch headquarters. If this is not an option, stabilize the banks applying the engineering standards and stabilization methods previously discussed.
- Grow a woody vegetation corridor between the existing channel and the farmed ground. Currently, farming occurs right up to the active channel.
- As with all activities, consider the costs of protection and maintenance with the alternative of no action or leasing or purchasing a corridor where the river is allowed to adjust on its own.

S6: This reach is most notable for the "blow-out" on the right bank, where the river is very actively widening. Currently, the landowner is losing ground at a fast rate, and is very vulnerable to more loss with a flood of even moderate magnitude. There may be some stabilization strategies that would be effective for the right bank; these have been discussed previously (see S2 recommendations). The hardened terrace option may prove to be the most effective as there is evidence on site that a vegetated terrace is viable. Without making light of the land owner's predicament, it should be noted that any substantive effort to inhibit further channel changes on this sight will prove to be very expensive and not without significant risk.



REACH C-6

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-7 REACH SUMMARY

SUB-REACHES: S1, S2, S3
LOCATION: Quilici Minor Property to Chavez Diversion

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: B4c/M/V S2: B4c/M,d/IV S3: B4c/m/N/A

General

The history of channel construction in C-7 is somewhat unclear, though local landowners suggest that at least S1 and part of S2 were straightened and leveed, or if not formally leveed, that levees resulted from channelization spoil piles on the banks. Corroborating evidence of a much more sinuous and tightly meandering historic channel can be observed from old meander scars on USGS topographic maps as well as aerial photos through S2. The upper segment of S3 appears unusually straight and suggests straightening at one time, though evidence of levees is absent; it is possible that waste material was used to level adjacent fields. Review of aerial photos from 1980 and 1990 suggest that the channel has been actively widening. Some of the most dramatic active channel widening can be observed on the Borda Ranch, where the active channel width more than tripled between 1980 and 1990. In contrast, upstream of the Chavez diversion in S3, the channel width appears to have narrowed since 1980. Aerial photo observations also coincide with our ground observations which labeled S1 and S2 as actively meandering (widening), while S3 was deemed only moderately meandering.

Bar types observed included alternate, point/mid, and point transverse types. A common feature of all of these bars was the fact that their highest surfaces were many feet above the low flow water surface elevation and that they supported no vegetation. In all three reaches, the elevations of these bars roughly coincided with stages of 2-year discharges. In essence, these bars represent a constantly mobile sediment supply since vegetation has been unable to establish on them. Moving downstream from S1 to S2, the stream becomes much more depositional; substrate D50's range from 0.25 inches to 0.125 inches. By S3, D50 is constituted of sands. Sorting is moderate in S1 and S2, and unsorted S3. Channel incision appears to range between 2 to three feet in S1 and S2, while in S3, the channel appears fairly well coupled with the floodplain. High flow (greater than 10-year discharge) access to the floodplain in S3 may be one important reason why an otherwise unvegetated and straight channel is not demonstrating as much instability as the upstream sub-segments.

Channel Capacity

S1: The surveyed cross-section at S1 consists of two active channels separated by a mid-channel bar. The elevation of this bar roughly coincides with the 1.25 to 2 year discharges. Incision of this channel has led to cross-section capable of containing 50-year and greater discharges. There is a notable break in slope in channel banks at the elevation of the 10-year discharge stage.

S2: The dominant part of this channel contains between the 2- and 5-year discharges. Gravel bars along the left bank are at elevations that correspond to the stage of between a 2 and 5-year flow. A secondary, smaller channel exists along the left bank which is likely inundated on an annual basis. The left bank is breached at flows between the 10- and 25-year discharge, while the right bank contains flows greater than the 25-year discharge.

S3: The lower elevations of the channel at S3 have grass-covered bars at elevations which correspond to the stage of annual maximum flows. The left and right banks are breached at the 10-year discharge. However, a levee on the left bank contains flows which exceed the 25-year discharge, and likely will contain flows up to or above the 50-year discharge.

Land Use

Land use is a combination of grazing, agriculture, and some housing in the floodplain. Housing, fencing, and outbuildings range from 20 to 100 feet from the bank toes. Some housing and infrastructure in S2 appear very vulnerable to even moderate magnitude floods.

Relative Stability

S1: Moderately Unstable   S2: Unstable   S3: Stable

General

Any levees which may have been constructed in S1 have been removed by lateral migration of the river as it is actively migrating into uncohesive fine grained outside bends. While some bar heights appear to be "fit" to a new floodplain elevation (roughly equivalent to a 2-year discharge), they are unstable due to lack of vegetation. In both S1 and S2, channel instability may be in part related to channel dewatering, which does not allow woody vegetation growth after seed set on the receding limb of the spring hydrograph. An obvious component of instability is the uncohesive, fine grained and frequently vertical banks on outside bends of the river. Heavy grazing in portions of S1 and all of S2 is severely limiting any potential stabilizing influence of channel fringe and/or overbank vegetation. While mostly agricultural ground is being lost in S2, outbuildings associated with the Borda Ranch may be threatened by continued river instability. Additionally, the rate of recent channel widening is particularly fast near the Glancy property, with the channel actively migrating towards homes on the left bank. These homes, and the Glancy property in particular, are threatened by the river during even moderate magnitude floods.

Bank Stability

S1: unstable S2: extremely unstable S3: moderately unstable

S1 banks are characterized by mostly vertical banks on outside bends between 6 to 9 feet failing through undercutting and gravitational forces. 40% of S1 banks are stabilized by woody vegetation. The extreme instability of S2 banks relates in part to the fact that 50% are unvegetated, 1:1 to vertical, with bank heights between 6 to 10 feet. Inside bends are dominated by large point bars whose highest points are near the floodplain surface. S3 is unusual in that 50% of the banks are unvegetated but stable, with 20% stable and vegetated and 30% unvegetated and stable. Again, the relative elevations of the channel and floodplain in this segment may be relieving the channel of erosional forces during large floods (greater than 10-year discharge) which would otherwise result in greater bank instability. Bank heights are 3 to 4.5 feet, with the majority between 2:1 to 1:1.

Vegetative Condition

The S1 riparian zone ranges between 15 to 20 feet and is generally confined to the points of contact between the historic floodplain and point bars. Scattered mature cottonwoods exist in both overbank areas. Riparian reproduction is very limited with little to no 0-10 year old woody plants; structural diversity is low. The S2 riparian area is well below potential with no vegetation in the active channel. Some decadent cottonwood stands are in the floodplain, though only in patches and with no reproduction evident. Overbank areas are overgrazed and include an unusually high percentage (80%) of bare ground. The S3 riparian zone is also well below potential; in-channel woody vegetation is totally absent and the overbank areas have only sparsely occurring mature cottonwoods. Non-native grasses and weeds are the dominant vegetative types; grazing pressure is moderate to high.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on *observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.*

While not necessarily a channel recovery strategy, protection of infrastructure at risk is generally recognized as a first priority in unstable systems. These fall into two categories: 1) those related to threat via channel migration and, 2) threat of flooding. In terms of flooding, these risks are more difficult to identify due to the relative infrequency of the 100-year magnitude flood. In light of the above, the following general recommendations are made:

- Conduct a risk assessment to identify private and public infrastructure at risk.
- Develop river stabilization or stress alleviating schemes for areas where significant private or public infrastructure is threatened by river migration.
- Re-assess the current zoning regulations regarding future development in flood prone areas. Insure this assessment relates to an accurate and current 100-year floodplain delineation.

Regarding infrastructure protection, bear in mind that engineered solutions should focus only on at-risk infrastructure at first. Also, as with all river projects, the impacts of the stabilization or floodplain management/development schemes on the hydrologic and geomorphic behavior of the river should be fully analyzed prior to implementation. *All* stabilization schemes should follow the following best practices:

- A complete assessment of the possible effects on upstream and downstream river stability from project implementation.
- Professionally designed and engineered treatments with clearly identified factors of safety and design criteria.
- The use of treatments which will also provide benefits for fish and wildlife.
- Identification of likely failure scenarios and the anticipated costs for long-term maintenance.
- Professionally installed treatments.

To stabilize this reach of the Carson River system, one would need to: 1) consider both lateral and vertical control measures, 2) the influence of a large in-channel sediment supply and the efficient transport of that supply downstream and, 3) the effects of large floods, which the Sierra drainages are very capable of producing. All engineered approaches should adhere to the Basic Design and Engineering Standard Practices for Channel Work described on page 30 or the main text.

- Active programs to remove aggraded gravel may have negative effects on existing channel-side vegetation. Any proposal of this nature should be rigorously scrutinized.
- Erosion protection on outside bends may be warranted should infrastructure become threatened following future flood events. Protection schemes should consider:

    1. Professionally designed and installed treatments including rock terrace bank toes in combination with bioengineered banks and bendway weirs.
    2. Strategies to stabilize levee toes with well installed riprap; perhaps in conjunction with the construction of a low terrace (similar to that found in stable reaches) and/or rock flow deflectors and an aggressive planting program on treated banks. Deflectors may be necessary to provide protection to the Burnell ditch, as it is vulnerable to capture by the river directly below the current diversion point.
    3. The construction of a terrace on both banks in conjunction with hidden rip rap protection on bank and/or terrace toes and extensive revegetation. The low-flow water elevations, well below even the midbank region, may stymie all but the most elaborate revegetation attempts.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.

- S1: The major problems with S1 relate to the channel's inability to grow riparian vegetation which over time will have the most stabilizing influence on the reach. We surmise that in addition to the active bedload, channel de-watering is inhibiting vegetative recovery. Furthermore, all flows up to the 50-year discharge are contained within the channel and therefore submit the bars to high scour forces. Given the channel's active migration and poor resistance to further erosion, we recommend:

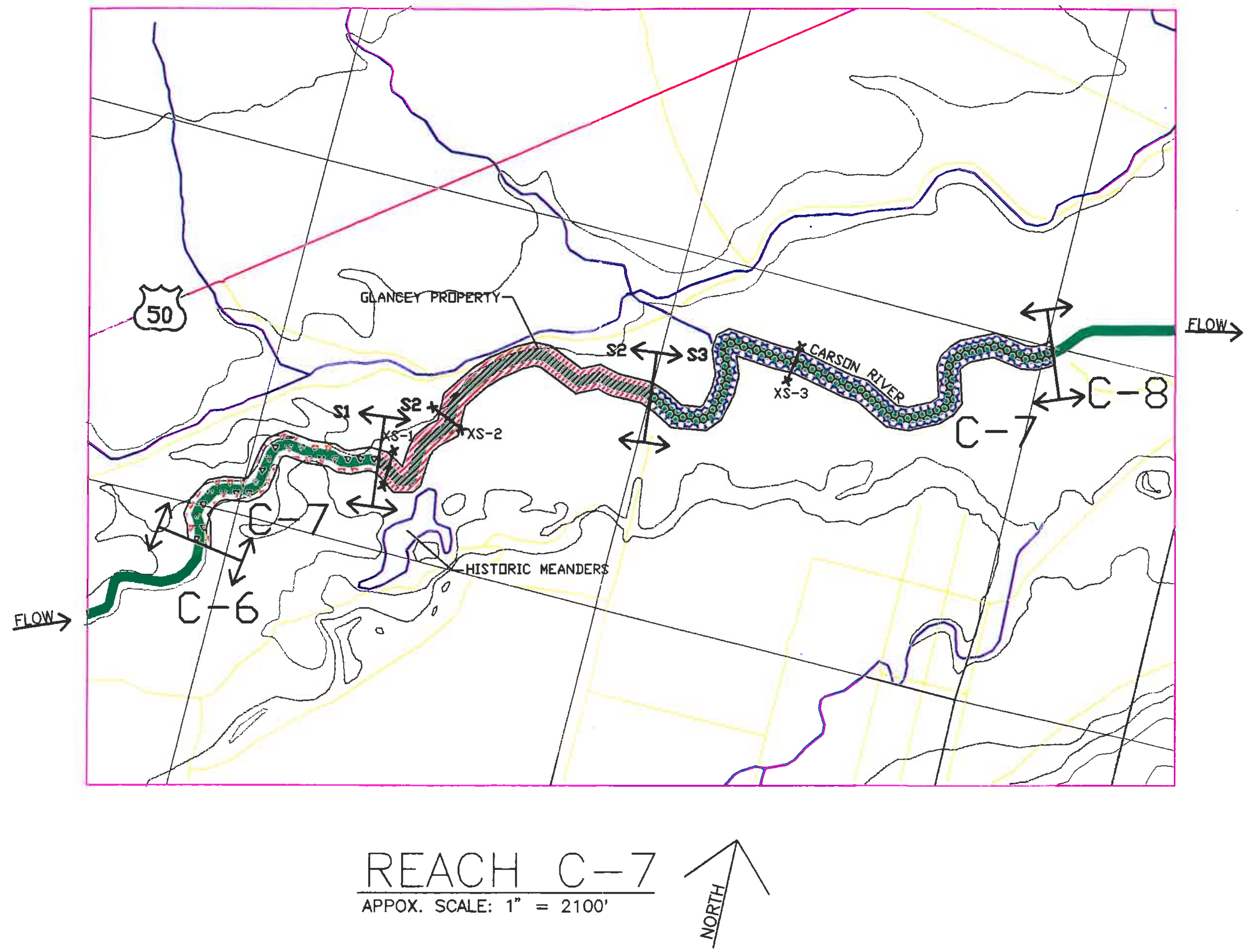
- A flood hazard assessment for homes in the potential active channel corridor. Active channel migration rates should be better quantified and water surface elevation models conducted. If hazards are identified for floods more frequent than the 100-year flow, a feasibility assessment should then be conducted to develop channel stabilization options. We strongly urge these assessments before more floodplain development takes place (development would increase potential flood losses).
- Active grazing management to promote better riparian condition should be implemented. While other factors (scour and summer low flows) are probably suppressing riparian potential also, grazing pressure is controllable with little effort.
- Any consideration of active restoration should take into consideration the instability upstream and the channel's tendency to gain more width.

S2: Channel instability is high in S2, jeopardizing several houses and ranch related infrastructure. Like S1, recovery of channel vegetation will be critical to the development of a stable channel in the long-term. This will not be possible with the current land use practices and the de-watering of the river. We therefore recommend:

- Local river managers work with the landowners to develop a cost-effective method for continuing to make a living off the property while enhancing the area's resistance to erosion. At that, this reach is very unstable, and would take a very significant effort to resist the forces encouraging the river to meander and increase the width of the active channel.
- A flood hazard assessment, per S1. Earth and rip rap work may prove to be necessary to provide the land owners adequate flood protection.
- It is strongly recommended that the Glancy's protect their banks with properly engineered and installed riprap prior to 1997 runoff events. Besides being in potential danger from inundation by floods (this spring's runoff was at the top of banks though well below a 100-year event), there is very little floodplain between the house and the actively eroding river banks. Banks in front of the Glancy home are unstable and highly vulnerable to additional erosion. To avoid unwise use of limited resources, it is recommended that sufficient funding be acquired such that the affected landowners can accomplish the work utilizing professional design and installation services.

S3: Despite the generally poor condition of the vegetative corridor in S3, it has decent potential for management induced recovery to a more stable channel. While it is impossible to predict whether the current channel stability will naturally remain, particularly given the large in-channel sediment load in reaches immediately above, any improvements in channel stability through land management changes should be considered the first line of defense. We recommend the following:

- S3 makes an excellent candidate for a riparian re-planting program coordinated with changes in riverside grazing practices. Without some change in grazing management, no riparian planting program will prove effective.
- An additional challenge will be the de-watered state of the channel during the growing season. Like upstream reaches, this may be a factor limiting riparian potential in this area. It is recommended, that if the landowner is willing, local agencies work with them to institute a pilot program aimed at greatly increasing the presence of woody riparian vegetation on channel banks and the floodplain.
- Based on the fact that an active floodplain is present in parts of S3, this sub-reach would make a good candidate for full channel restoration, though consideration should be given to its position in the watershed (downstream of major instability). However, if proven successful, it could become a model for active restoration programs elsewhere on the river which have similar geometry and site conditions.



REACH C-7

APPOX. SCALE: 1" = 2100'

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-8 REACH SUMMARY

SUB-REACHES: S1, S2
LOCATION: Chaves Diversion to Break-a-heart

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications
S1: C5c/C,M/IV S2: B5c/e/III

General
Reach C-8 is generally incised, aggradational, actively changing and unstable. Some of the most notable features in the reach are the presence of very large and unvegetated alternate lateral bars with shear faces up to 5 feet, indicating that a very large volume of material was in transport during the events which created the bars. The reach is widening and enlarging its cross-section at both ends and may in fact be more stable now than it will be over the passage of the next several years. Notable bank erosion in S1 and below (down towards the canyon "neck" on the Chaves Ranch) includes vertical eroding banks of unconsolidated fines extending up to 9 feet. Channel shape in S1 is almost compound though its regularity is altered by the channel's tendency to migrate into soft banks. While land owner access prevented a full inventory of the middle section of C-8, review of aerial footage shot earlier in October, 1996, suggests that instability patterns noted in S1 extends through this section as well. Past incision of this reach is very evident, though a relatively narrow channel cross-section has been preserved in S2. However, there was field evidence, such as incipient cut-off channel development and steeply undermined vertical banks, which suggest that the channel is enlarging.

Channel Capacity

S1: The dominant portion of channel at this cross-section contains the 10-year discharge. There is a terrace on the left bank at this elevation (10-year stage) which is roughly 175 feet wide. The elevation of the terrace/bar along the right bank is equivalent to the stage of the 25-year discharge. All flows up to and above the 50-year discharge are contained by both banks, while the right bank contains 100-year flows and above.

S2: The surveyed cross-section in S2 consists of a low flow channel with lateral bars on the right and left banks. These bars are likely inundated during numerous flows on an annual basis. Both the left and right channel banks contain up to the 25-year flow.

Land Use

Grazing and agricultural uses are dominant in C-8. With the exception of the Chaves Ranch headquarters, there is very little infrastructure in the floodplain.

Relative Stability

Unstable

General

Instability in S1 and S2 are related to the large sediment supply, the channel's tendency to gain channel width following an episode of incision, and highly erodable banks. The net result is a channel which can rapidly change its active channel width during a single flood event. Several developing scallops were observed, where lateral migration of up to 40-60 feet in the last few years is indicated. This pattern is similar to some other reaches upstream, and perhaps suggests that the channel will continue to be naturally unstable for some time to come. Vegetation within the channel is virtually absent in S1 and downstream towards S2, so there is effectively very little resistance to continued bank erosion. The channel in S2 is in somewhat better condition in terms of bank vegetation, as there is some reasonably thick growth on narrow alternate bar/terraces within the channel. Because of this increased resistance, the rate of change in S2 may not be as high as the upper subsections. Additionally, S2 is likely affected by the Houghman and Howard Diversion, which is downstream approximately 1 mile from our S2 cross-section. The fall over this diversion is approximately 10 feet; it may have been favorably controlling incision in S2 in recent history which has promoted greater stability.

Bank Stability

S1: unstable S2: unstable

Almost half of S1 banks are 1:1 to vertical, with most tending towards vertical. The dominant mode of failure is undercutting and gravitational. Erosional areas are non-specific, occurring on outside bends, straight sections, and inside bends. Bank material consists of highly erodable fines which are very uncohesive when wetted. Only 40% of the banks are vegetated; these banks are dominated by non-native forbs and grasses. S2 banks are also undercutting and failing through gravitational force and range form 6 to 9 feet in height. 65% of the banks are unstable and 85% range from 1:1 to vertical. Bank material is uncohesive homogenous fines.

Vegetative Condition

The S1 riparian zone ranges between 5 to 10 feet, and is limited to the outside fringes of the active channel. The historic floodplain is dominated by old cottonwoods and sage brush. Generally, the woody plant component is missing in the channel, with the exception of cottonwood seedlings which had a good seed set this spring but are now showing evidence of moisture distress. De-watering of the channel may be inhibiting development of the young age classes of woody vegetation. In contrast, the fringe area between the edge of lateral bars and the historic floodplain in S2 show better riparian development and recruitment. The channel fringe riparian widths through here are 5 to 10 feet. The floodplain species through some areas of S2 appear to be in reasonable shape, though are not reproducing at their current elevation.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

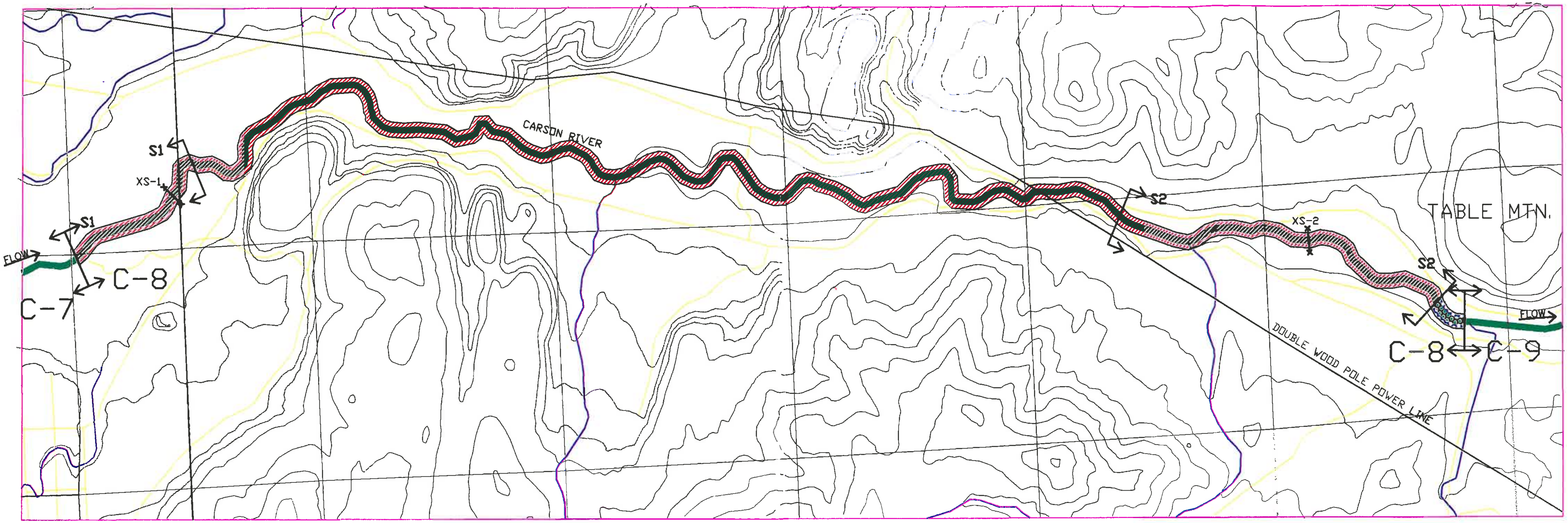
This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.

S1: Given the lack of threats to infrastructure and the relatively large extent of instability in S1, very little can be recommended from a structural stability perspective. Like the entire river corridor, any efforts to manage for the propagation of woody channel vegetation should be encouraged. However, it is likely that this section will undergo further changes before it may approach a more stable state naturally. Channel behaviors noted included a tendency for rapid channel widening. Given the bank instability throughout, it is likely that even common magnitude floods will continue to erode the channel until a quasi-stable channel width is achieved.

S2: The same observations for S1 hold for S2. Given its slightly higher resistance to bank erosion provided by the riparian fringe vegetation, this sub-reach may change at a slower rate than S1. However, given the upstream instability and large in-channel and mobile sediment supply, it is not difficult to envision a continuation of an unstable pattern through the near future. The absence of sufficient flows to support channel fringe vegetation during the summer months may perpetuate the area's instability. Furthermore, channel bars and/or terraces are only inundated at approximately 10-year flows and so are not receiving annual or even less frequent moisture inputs. Wild cards in this scenario may include the absence or occurrence of large floods in the near future and the integrity of the Houghman and Howard Diversion dam. An absence of floods may promote better channel stability while a large flood may dramatically change the existing conditions.

Based on the relative lack of infrastructure, upstream instability, the degree of instability on sight and the perceived tendency for future channel enlargement, we recommend that structural approaches for stabilization not be explored in either S1 or S2.



REACH C-8

APPOX. SCALE: 1" = 2300'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-9 REACH SUMMARY

SUB-REACHES: S1, S2
LOCATION: Houghman and Howard's Ditch Diversion to Buckland Station Bridge

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: B5c/E/IV S2: B5c/E/IV

General

C-9 is a meandering, incised channel which shows signs of significant active channel shifts between existing channel banks. Aerial photos from 1980 and 1990 reveal that there has been little change over that decade in the location of channel margins or in overall sinuosity and planform character. However, these photos, and ground observations, show significant active channel shifts within the channel margins. In some short sections (half mile sections), sinuosity and planform show extreme changes, though overall for the reach, these attributes are relatively constant. In other words, this reach is very dynamic, but general planform attributes remain fairly constant.

Two prominent diversion structures exist, one at the top of the reach and one which separates S1 from S2 at the State Park (Buckland Ditch Diversion). These diversions appear to have a tremendous effect on channel character in that channel incision is greatest below the diversion and decreases downstream as the backwater effects of the next downstream grade control play a role. Channel character upstream of the diversions is much more stable, with low banks, channel access to floodplains at 2- to 5-year flows, and greater bank stability. However, below the diversions, the channel is much more dynamic and incised, with flows up to the 50-year discharge contained in the channel. While the diversions appear to be contributing to channel stability above the diversions, it is possible that these diversions initiated channel instability by interrupting bedload transport dynamics, leading to incision.

Channel Capacity

S1: Two cross-sections were surveyed at the top of S1 - one above and one below the Houghman and Howard Diversion dam. Above the diversion, the channel cross-section is small relative to up- and down-stream areas. A terrace has formed at an elevation which roughly corresponds with annual maximum flows. The floodplain elevation on both banks roughly corresponds with the stage of a 5-year discharge. Below the diversion dam, the channel cross-section increases tremendously. It is incised and contains the 25-year discharge on the right bank, and greater than the 50-year discharge on the left bank. A bar form on the right bank roughly corresponds with annual maximum flows.

Two additional cross-sections (C9-3 and C9-4) were taken through a meander bend and at a transition between a meander bend and a straight reach. At the transition cross-section, there is a bar form along the left bank. The elevation of this bar is approximately equivalent to the stage of a 1.25-year discharge. While the 10-year discharge is contained within the channel, the lateral extent of the survey did not cover enough to estimate the stage of greater discharges. The second cross-section, through the axis of a meander bend, shows multiple bar elevations in the form of terraces. Elevations of these terraces roughly correspond with the stages of the 2-, 5-, 10-, and 25-year flows. In other words, bar form terraces have apparently been formed during relatively large magnitude events.

A fifth cross-section was surveyed across a well vegetated historic meander bend and the active channel. The elevation of the historic meander bend (now well vegetated with up to 30-year old vegetation), is equivalent to the 5-year stage at the active channel edge, and the 2-year stage at the back side (along the bank). Bar/terraces within the active channel occur at or near the elevation of annual maximum flows. The channel overall contains 10-year or greater flows.

S2: No slope was measured at this cross-section, so no hydraulic analysis was conducted.

Land Use

Land use throughout C-9 is limited to grazing, with some recreation in the State Park lands.

Relative Stability

Moderately Unstable to Unstable

General

Channel stability is described as moderately unstable to unstable. For the most part, channel stability appears to be related to the location of diversion structures, as described above. In many areas, the channel appears to be recovering from initial incision and instability in that bars exhibit various age classes of riparian species including willows and cottonwoods. Depositional bar forms also show a terraced character, with elevations corresponding to flow stages between the 5- and 25-year discharges. Incision may have been episodic. In S2, there exist terraces (erosional, as opposed to depositional bar terraces) which are elevated relative to active channel elevations, but lower than the floodplain. These terraces are old meander bends and have 6 to 8 foot high steep banks up to the floodplain, yet are 6 to 8 feet above the active channel. Vegetation on them is 20 to 40 years old and may indicate two periods of incision. Further investigation of plant ages on these terraces and relative elevations of floodplain, terrace and active channel bars may shed light on episodes of incision.

The Carson River flows through an area of large substrate size immediately below the diversion which separates S1 from S2. This appears to be an area of bedrock which offers some degree of channel stability for a short stretch. However, incision appears to have occurred despite this attribute, though it may have been checked to some degree. Throughout C-9, sediment supply is exacerbated by the availability of sediment from bare banks and unvegetated bars.

Bank Stability

S1: unstable S2: unstable

Banks throughout C-9 are unstable, on both sides of the channel. Bank heights range from 3 to 4 feet above diversions, to 15 feet in incised sections. The majority of banks are 1:1 or steeper and largely unvegetated due to their steepness, regularity in failure, and elevation above the active channel. Some isolated areas of riprap exist, which exhibit varying degrees of effectiveness and utility. While the majority of bank erosion and instability occurs at outside bends, inside bend banks are unstable and lacking in vegetation regeneration. Inside bends have large depositional bars and show some regeneration, but are generally backed by steep, eroded banks.

Vegetative Condition

With the exception of those areas upstream of diversion structures, the floodplain adjacent C-9 is elevated relative to the active channel from 6 to 15 feet. Vegetation on the floodplain consists of mature and decadent cottonwood forests and sage brush and grasses. Cottonwood forests coincide with historic meander patterns as demonstrated by their arcuate boundaries. Bank vegetation is largely absent throughout the reach, with the exception of upstream of diversion where banks are vegetated and more stable. Most bars throughout the reach show varying degrees and ages of riparian species regeneration. These stands are generally long narrow populations of similar aged cottonwoods or willows which parallel the active channel in the middle of the bar form. High flows apparently scour bars along the channel margins where meanders are cut off. Age classes of these regeneration stands range from sprouts to 20 year old cottonwoods. They exist at elevations approximately 5 feet above active channel elevations, indicating that this may be the appropriate elevation for a floodplain relative to the current channel elevation. Tamarisk are present in some locations and indicate the early stages of potential tamarisk invasion.

Channel Recovery And Land Management Recommendations

NOTE TO READERS:

This report was originally submitted in December of 1996, prior to the New Year's Flood of January 1997. It should be noted in reading this document that the conclusions and recommendations stated in this report are based on observations which were made previous to the geomorphically significant flood event. The physical state of much of the observed areas has been significantly altered. In many reaches and subreaches, physical change resulting from these floods has been so significant as to render some recommendations inappropriate. Where such changes have been observed by local land managers, their opinions as to the appropriateness of recommendations should be observed. However, in our opinion, while site specific and short term recommendations may be less appropriate following the flood, general and long-term management considerations are still appropriate and relevant on a watershed scale.

While not necessarily a channel recovery strategy, protection of infrastructure at risk is generally recognized as a first priority in unstable systems. These fall into two categories: 1) those related to threat via channel migration and, 2) threat of flooding. In terms of flooding, these risks are more difficult to identify due to the relative infrequency of the 100-year magnitude flood. In light of the above, the following general recommendations are made:

- Conduct a risk assessment to identify private and public infrastructure at risk.
- Develop river stabilization or stress alleviating schemes for areas where significant private or public infrastructure is threatened by river migration.
- Re-assess the current zoning regulations regarding future development in flood prone areas. Insure this assessment relates to an accurate and current 100-year floodplain delineation.

Regarding infrastructure protection, bear in mind that engineered solutions should focus only on at-risk infrastructure at first. Also, as with all river projects, the impacts of the stabilization or floodplain management/development schemes on the hydrologic and geomorphic behavior of the river should be fully analyzed prior to implementation. *All* stabilization schemes should follow the following best practices:

- A complete assessment of the possible effects on upstream and downstream river stability from project implementation.
- Professionally designed and engineered treatments with clearly identified factors of safety and design criteria.
- The use of treatments which will also provide benefits for fish and wildlife.
- Identification of likely failure scenarios and the anticipated costs for long-term maintenance.
- Professionally installed treatments.

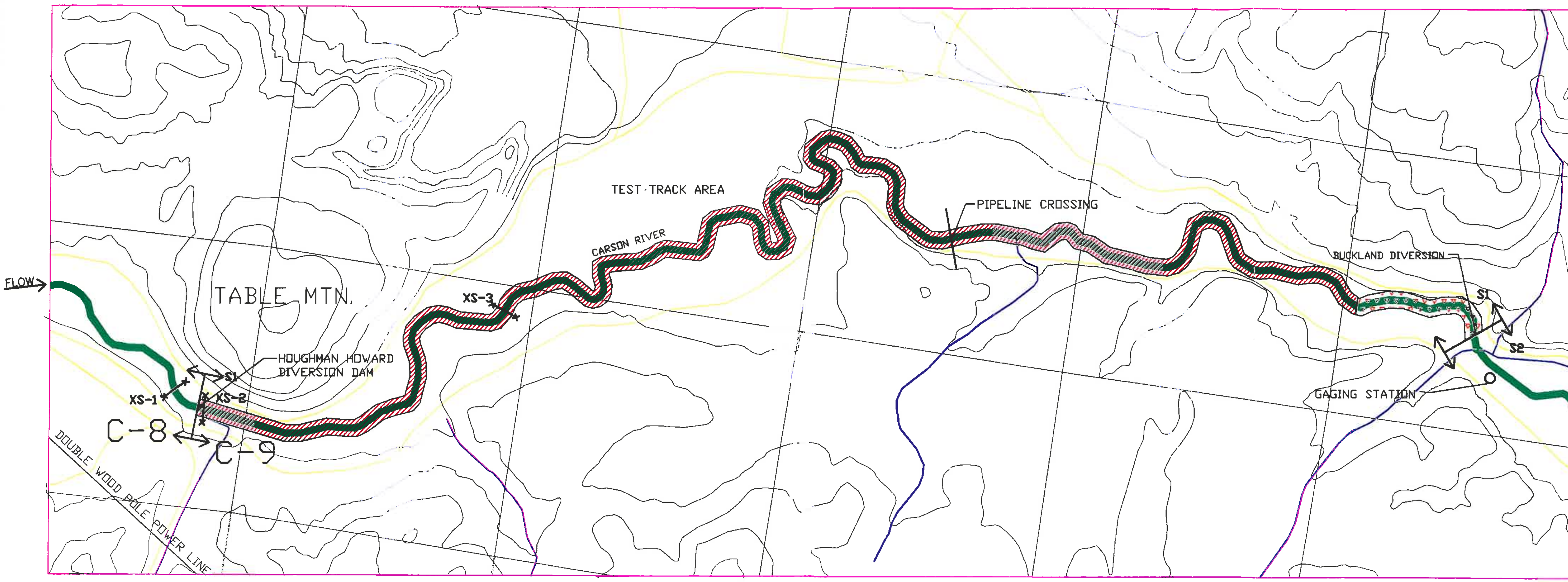
To stabilize this reach of the Carson River system, one would need to: 1) consider both lateral and vertical control measures, 2) the influence of a large in-channel sediment supply and the efficient transport of that supply downstream and, 3) the effects of large floods, which the Sierra drainages are very capable of producing. All engineered approaches should adhere to the Basic Design and Engineering Standard Practices for Channel Work described on page 30 or the main text.

- Diversion Structures: We recommend that loose rock diversion structures be replaced with more permanent diversion structures or pumping galleries, in conjunction with the consolidation of diversion points to eliminate unnecessary structures. Conceptually, if the existing permanent structures could be re-engineered to allow for greater bedload transport during moderate and frequent high flow events, overall sediment transport continuity on the river may be improved. Replacement with pumping systems would allow for natural river function without the negative effects of diversion structures. The benefits of improved sediment transport may be difficult to quantify, though allowing the river the "freedom" to move bedload downstream in as natural a manner as possible is consistent with aided natural recovery options.

- C-9 is relatively undeveloped, and consequently little is threatened by channel migration or instability. However, one area of bank instability adjacent to a road near the test track may threaten this road over time. Existing riprap appears undersized and ineffective. Bank instability at the location of the pipeline crossing also should be addressed to protect the pipeline. We recommend both grade control and bank riprap to protect the pipeline crossing.
- The majority of lands adjacent to reach C-9 are grazing lands with no riparian exclusion. Those areas which do not have such grazing impacts, namely those in State Park land at the bottom of the reach, exhibit greater

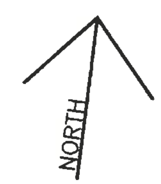
bank stability, riparian species regeneration, and riparian zones. Consequently, grazed lands should be managed to promote riparian regeneration.

- Consideration should be given to irrigation withdrawal structure designs which allow for bedload transport during high flows as there is a strong correlation between incision depths and diversion locations.



REACH C-9,S1

APPOX. SCALE: 1" = 2100'

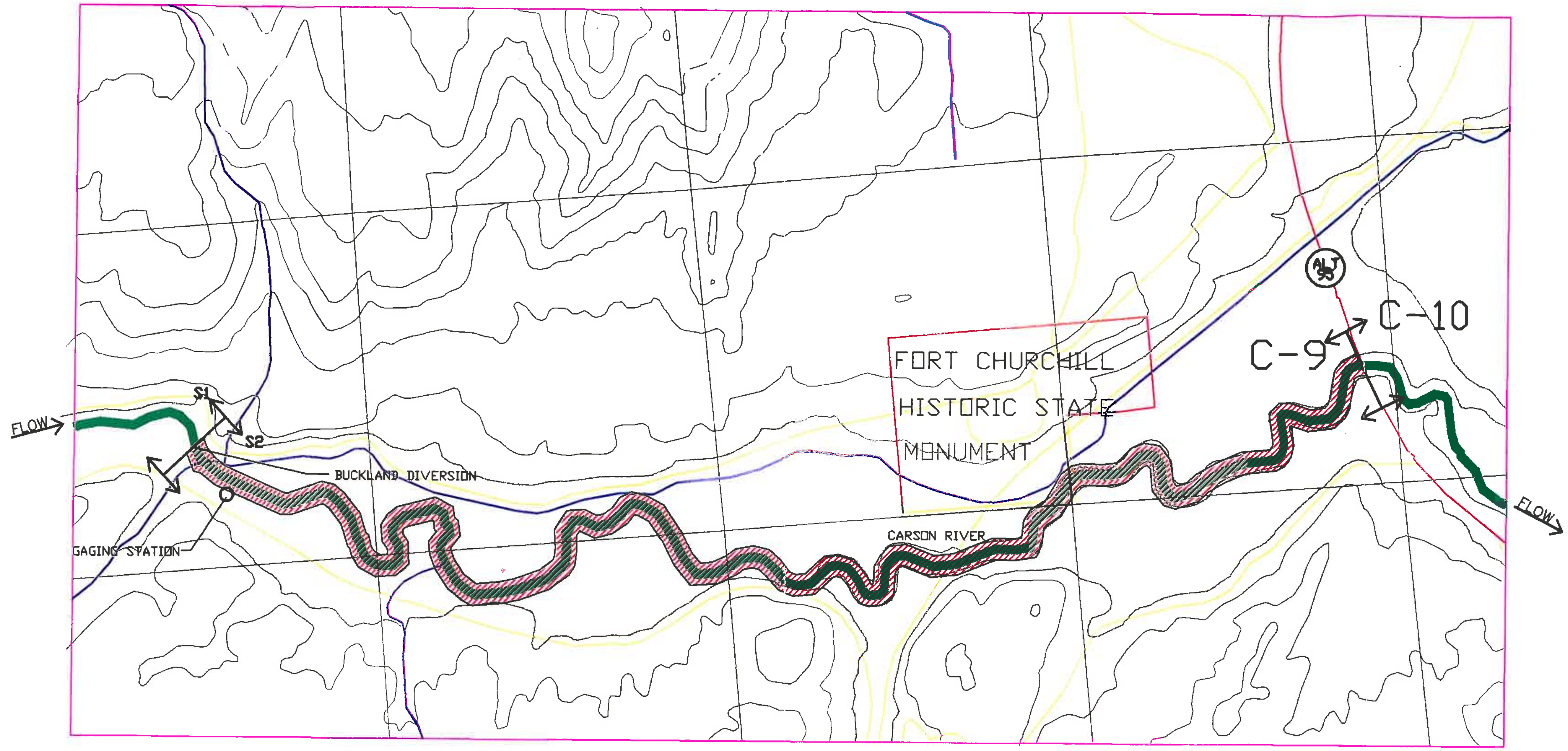


LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE



REACH C-9,S2

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE

C-10 REACH SUMMARY

SUB-REACHES: S1, S2
LOCATION: Buckland's Station to Lahontan Reservoir

Geomorphic Setting

Rosgen/Downs/Harvey-Watson Classifications

S1: C-5c/E/III S2: C-5c/m/NA

General

Reach C-10 is divided into two sub-reaches. The boundary, however, is somewhat arbitrary as there is a progression of change in channel character throughout the reach. The upper sections of the reach (S1) are characterized by moderate incision, generally unstable banks and active lateral migration, while the lower section of the reach (S2) is a stable channel which is well paired with its floodplain and relatively stable banks. From top to bottom, this reach increases in stability and relative channel health. S1 is incised, and consequently high flow energy is not dissipated on the floodplain. While the grade appears stable, there appears to be an excess of fine sediment supply from upstream and local bank erosion. Additionally, lateral instability is evidenced by continuous unstable banks.

The cross-section of S2, relative to all upstream reaches, is much smaller. Channel depths and channel width are a fraction of those upstream and numerous side channels, as well as the floodplain as far out as 200 feet from the channel, show debris caught during regular high flows. This reach is a C-5 channel, with bank instability limited to outside bends and moderate lateral migration rates.

Aerial photos were not available for this reach, so historic channel planform cannot be interpreted beyond ground observations.

Channel Capacity

Channel conveyance decreases in a downstream direction from the top to the bottom of the reach. As stated above, this occurs along a continuum, rather than at a point.

S1: The uppermost cross-section surveyed in S1 is through a meander bend. The dominant portion of the channel contains the 10-year discharge, though a side channel at the bank-side of the bar likely conveys flows greater than the

2-year discharge. The point bar at this location has a terraced nature, with terrace elevations corresponding to flows between the annual maximum discharge and the 10-year discharge. The floodplain elevation roughly corresponds with the stage of the 10-year discharge.

Two additional cross-sections were surveyed further downstream. Their conveyance is approximately the same, perhaps a bit lesser, than that upstream, containing between the 5- and 10-year flow. The channel at this location exhibits some terraces, the elevations of which correspond to annual maximum flows.

S2: Two cross-sections were surveyed in this sub-reach. The first shows 3 channels, all of which likely flow during annual maximum events. The floodplain elevation at this location roughly corresponds with the 1.25- to 2-year discharge. The floodplain at the location of the second cross-section is at a low elevation relative to the channel. The lowest return interval for which hydraulic analysis was performed, the 1.25-year flow, apparently overtops the channel banks. In other words, the floodplain area adjacent to the channel is likely inundated on a near annual basis.

Land Use

Land use throughout the reach is limited to grazing.

Relative Stability

Moderately Unstable to Stable

General

As discussed above, overall channel stability increases in a downstream direction from moderately unstable to stable. It is presumed that the relatively constant base level of the reservoir has checked incision which is common throughout upstream reaches. Furthermore, no diversion structures are present in this reach. While grade appears stable throughout the reach, lateral instability is dominant in S1, and a minor problem in S2. Lateral stability issues in S1 are driven by channel incision which leads to excessive sediment and increased erosional forces on the banks. In S2, the minor bank instability may be exacerbated by grazing practices.

Bank Stability

S1: unstable S2: moderate

Bank stability, like general channel stability in C-10, increases in a downstream direction and is largely attributed to bank height. Bank heights at the top of the reach are up to 10 feet, while those at the bottom are as little as 2 feet. Where bank heights are lower, the floodplain is coupled with the channel, meaning that regular high flows are dissipated on the floodplain. This leads to greater riparian and bank vegetation which increases stability. The degree of bank vegetation increases and bank slopes decrease in a downstream direction.

Vegetative Condition

S1: Riparian vegetation is limited or non-existent in much of S1. The floodplain is elevated relative to the active channel, precluding moisture regimes which are conducive to riparian vegetation. Furthermore, grazing impacts restrict regeneration. Some riparian species are beginning to colonize bars.

S2: Riparian vegetation is much more common in S2, but given the relative channel stability and moisture regime, there is a noticeable lack in riparian vegetation densities. Grazing has had observed impacts on regenerating vegetation. While there is a full range of age classes, this area is far below its potential for riparian zones. S2 has some wetland environments associated with historic channels and cutoff meanders. Tamarisk invasion is at an early stage.

Channel Recovery And Land Management Recommendations

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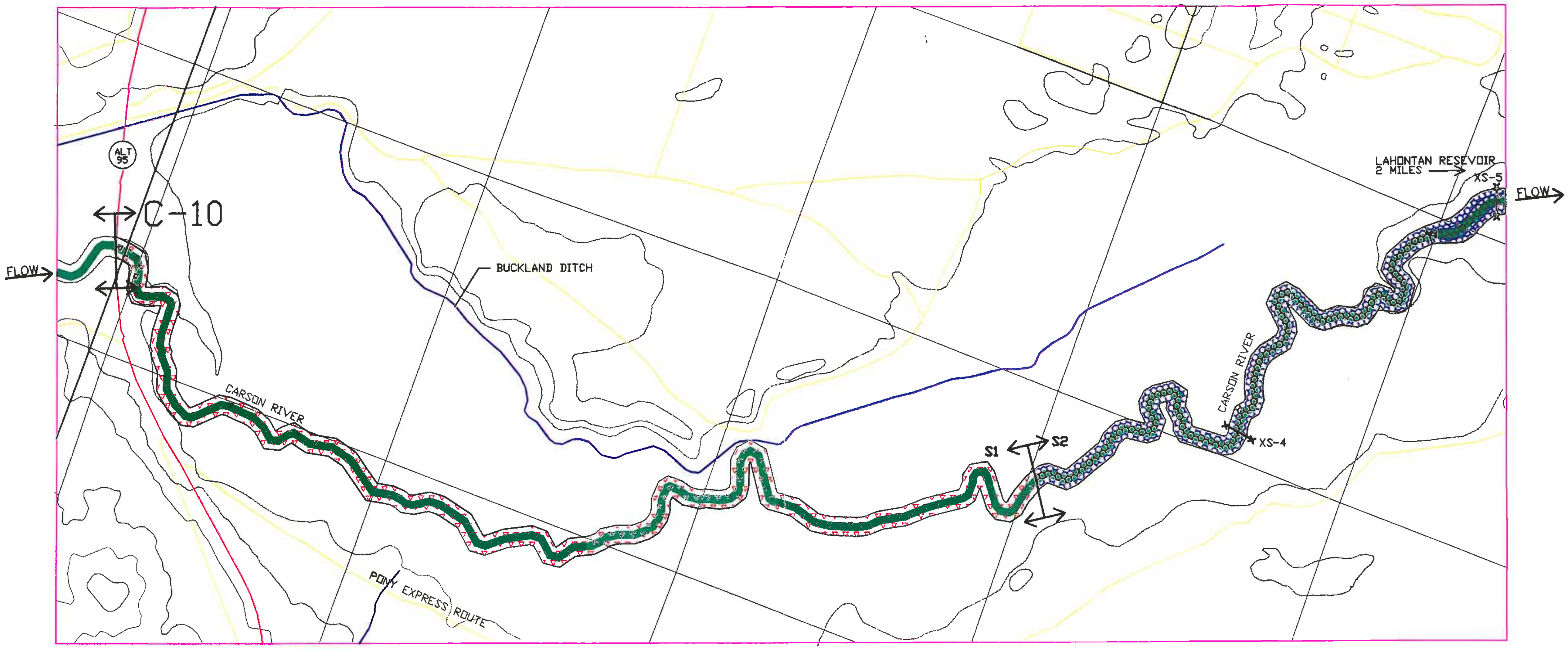
- Channel recovery and land management recommendations for C-10 are limited to management of grazing practices. In S1, an aggressive riparian grazing management approach is recommended as there is little riparian vegetation and moisture and bank conditions preclude rapid natural re-establishment and regeneration. In S2, however, more moderate approaches to riparian grazing management are recommended. Options may include seasonal exclusions or decreasing the number of cattle allowed to graze riparian areas.
- Levees adjacent to the channel in the lower half of S2 appear to perform little function. Furthermore, they act to restrict flood flow dispersion and riparian and wetland acreage. Removal of these levees should be considered.



REACH C-10

APPOX. SCALE: 1" = 2100'

NORTH

LEGEND

- CARSON RIVER
- ROADS
- MAIN ROADS
- TRIBUTARY CHANNELS/DITCHES
- CROSS SECTION

STABILITY

- EXTREMELY UNSTABLE
- UNSTABLE
- MODERATELY UNSTABLE
- STABLE
- VERY STABLE