LOWER HASSAYAMPA RIVER
RECOMMENDATIONS FOR DEVELOPMENT

Prepared for

Flood Control District of Maricopa County

THE FLOOD CONTROL DISTRICT OF MARICOPA COUNTY

2801 W Durango St
Phoenix, AZ 85009

December 27, 2011

Prepared by

R₂D

River Research & Design, Inc.

4359 N Pine Featherville Rd
Featherville, ID 83647
www.r2d-eng.com

Registered Professional Engineer (Civil)
CERTIFICATE NO.
36225
GARY E.
FREEMAN
Date Signed 12/29/11
ARIZONA, U.S.A.

Expires 6/30/2013

LOWER HASSAYAMPA RIVER
RECOMMENDATIONS FOR DEVELOPMENT

December, 2011

OVERVIEW

The Hassayampa River is a sand bed river and, as a result, it is more sensitive to changes in floodplain widths and flow depths than other rivers in Maricopa County such as the Salt, Gila, Agua Fria, and most washes. The majority of large rivers in the county are gravel or cobble bed rivers that armor during most flows. This armor reduces the impact of encroachments into the floodplain as well as the impacts of mining. Such is not the case for the Hassayampa River. The lack of this armor layer means that changes occur rapidly without the protection of an armor layer made up of gravel and cobble layers.

Since the Hassayampa River is a sand bed river, changes to the rivers flow area can have a major impact on channel stability. If the river is encroached beyond a critical point (or mined too deeply) it will very likely begin to narrow and deepen rapidly and will likely start to headcut upstream from the encroached/mined section. This reduction in width normally creates a headcut that can move for many miles up the river and destabilize the river and all of its tributaries. To assist developers and sand and gravel mining operations these suggested limitations or guidelines have been developed in coordination with Maricopa County.

The Hassayampa River from the Gila River confluence to the mouth of the Canyon near Morristown functions as a continuous sediment reservoir / transport reach and recommendations for the study reach (from the Gila River to the CAP crossing) are valid throughout the entire reach. Any changes made in the study reach both impact, and are impacted by changes to, the river above the study reach. Observations and recommendations contained herein are based not only on work performed during this study but on work performed by R2D for MCDOT (The CK Group 2007) and from other site visits. The headcuts and tailcuts observed following the 2010 flood event and the observation of a large number of sand bed streams nationwide are the primary basis for these recommendations for the Hassayampa River. The 2010 event was approximately a 20 year event and caused the channel to lower by 12 feet at the upstream brink of the Pioneer Pit. The channel lowering tapered to approximately one foot in depth at a distance of approximately 4,000 ft from the upstream brink of the pit.

Reviewing the data from this study (R2D 2011) and the MCDOT study conducted by R2D (The CK Group 2007) it appears that the Hassayampa River immediately downstream from the canyon at Morristown is very likely depositional and as such should be protected as a broad shallow floodway (See Figure 1). This area downstream from Morristown is the first significant area where the river can deposit sediment that it is carrying through the more restricted areas upstream from Morristown. There is a short section just upstream from Wickenburg where the river widens slightly (See Figure 1) and begins to deposit sands and gravels (as observed during the design of the Wickenburg

Bypass for ADOT, Jacobs (2008) but when the river reaches the broad floodplain south of Morristown the flows expand suddenly and large amounts of sand begin to deposit. A constriction of the river sufficient to change the regime from the wide shallow river that is found below the Morristown Canyon to a narrower and deeper river anywhere in the reach from Morristown to the UPRR bridge will cause erosion or, at best, simply move the depositional area downstream to the end of the constrained reach. (See the reach below the US 80 bridge after the 2010 event for an example of erosion in a constrained reach.) This would have major complications for bridge capacity and design downstream. If the river is laterally constrained to too great of an extent the sediment supply will be limited and erosion from the bed and bank will occur. This will create major problems due to erosion, deposition and loss of river stability in both the upstream and downstream reaches.

The Hassayampa River from the end of the Morristown Canyon to about two miles upstream of the Pioneer pit also appears to be slightly aggradational (depositional) based on the observation that some of the active braids are higher than the inactive braids (See Figure 2). If the river is depositional in this reach the river will tend to slowly increase in elevation over time. This could lead to expansion of the 100 year floodplain as the river aggrades. The narrowing of the floodway due to human encroachment will move this excess sediment downstream and cause additional aggradation in the lower reaches of the river – immediately downstream of the narrowed reach. Given the change in river morphology at the end of the Morristown Canyon it is very likely that the river is depositional but for the moment the sediment load appears to return to a near balanced condition before reaching the Pioneer pit.

As a result of this study a number of recommendations have been developed. These recommendations are discussed individually below but the three of the most important recommendations are: 1) it is recommended that the floodway be left very wide to allow the river to deposit its excess sediment load in an area where it will not impact development and infrastructure, *2) bridges should be designed with this in mind such that additional bridge height is incorporated into the design so that if the river aggrades the bridges do not become too low to pass the design events, and 3)* an accompanying recommendation for a monitoring plan should be implemented to help the County in determining if the river is stable or aggradational in the various reaches below Morristown.

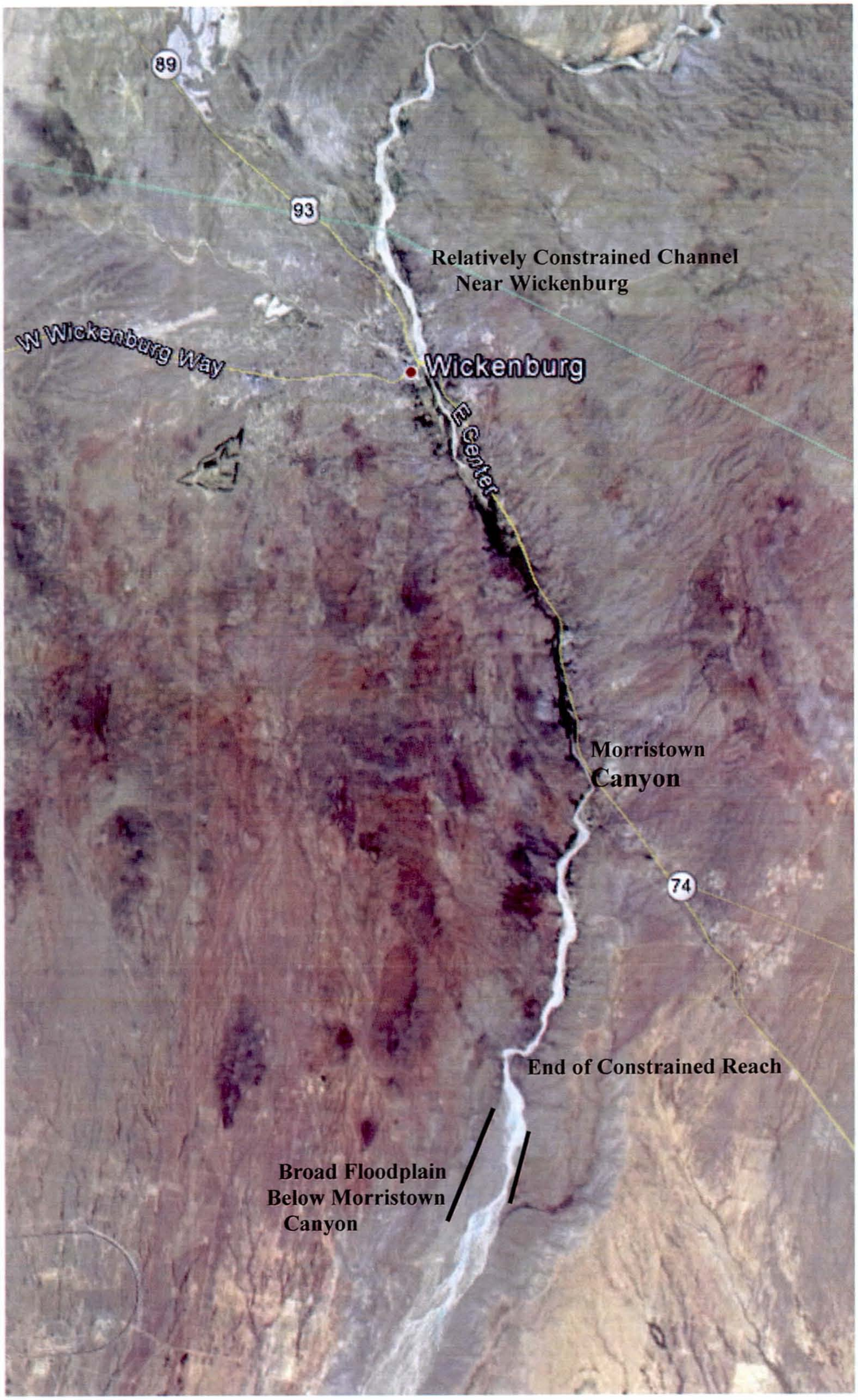

Figure 1. Aerial of Hassayampa River near Wickenburg, AZ showing constrained reach upstream and broad depositional reach downstream.

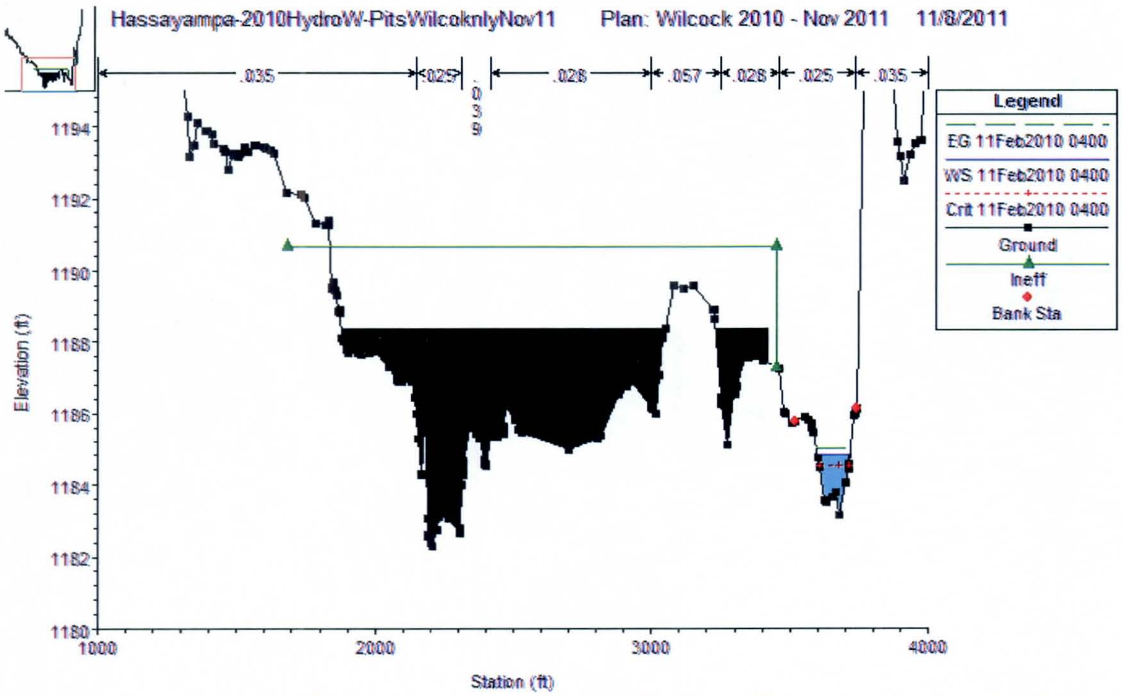

Figure 2. Cross Section 18.35 Showing the Active Braid (in Blue) Higher than the Inactive Braid (Lower and in Black).

SAND AND GRAVEL MINING RECOMMENDATIONS

The County's current requirements for the review of sand and gravel mining permits should be followed at a minimum. The requirements currently include:

a) Sediment Transport Modeling. Sediment transport modeling is required to show that the mining operation will not cause more than 1.0 ft of scour to leave the owners property[1]. Sediment transport models currently recommended are HEC-6T and FLUVIAL-12. HEC-RAS[2] is useable but did not give results as accurate as those obtained from HEC-6T and FLUVIAL-12. These recommendations are based on a model review comparing model results to the observed river channel based on the 2010 flood event. Current acceptable equations for use in the models are:

[1] The River Mechanics Branch policy is that no adverse impact (i.e. 0.0 ft of scour) should leave the mining property but given the accuracy of the topography and the limitations of model accuracy the one-foot criteria is accepted as being reasonable.

[2] HEC-RAS was evaluated based on observed data and did not perform as well as HEC-6T and FLUVIAL-12. The only equation that produced acceptable results in limited testing was the Engelund Hansen equation. This equation predicted headcut lengths but over predicted depths. Further analysis is needed.

HEC-6T – 1) Toffaleti + Meyer-Peter & Mueller Equation
2) Yang D_{50} Equation
3) Toffaleti Equation
4) Ackers White Equation

FLUVIAL12 – Engelund Hansen Transport Equation

HEC-RAS – Engelund Hansen Transport Equation (not highly recommended at present).

b) Inflow areas should be gradually sloped into the pits to help prevent vertical headcuts from forming during smaller flood events.

c) All other County guidelines or policies regarding setbacks, utilities, excavation depths, berms, and protection should be followed as they are or will be specified for sand bed rivers.

In addition to the methods for analyzing the potential for problems the following recommendations are applicable to the Hassayampa River:

1) **The upper reaches of the river from the Morristown canyon to approximately 2 miles above the Pioneer mining site appear to be depositional. If this is the case, sand mining may be viable to use in the upper reaches to mitigate some aggradation but if channelization occurs the minimum 1st floor elevations downstream from any significant channelization should possibly be raised.**

It appears that the upper reach of the river (immediately below the Morristown canyon) is depositional. This observation is based on 1) the change in river morphology, and 2) the main channels being perched (i.e. higher than the minimum elevation in a cross section) in the reach being modeled several miles downstream from the change in morphology at Morristown Canyon. Other studies have identified this reach as stable (Fuller 2004) and further study would likely be necessary to verify this observation. Based on the observation above, the river appears to be slowly aggrading. Given the small differences between active and inactive braids the river is likely close to being in balance in the lower reach which was the focus of this study. If this observation is accurate, sand mining may mitigate potential deposition/ aggradation to some extent but if care is not used the mining could cause erosion downstream from the pits. Care should also be used in setting the elevation of developments along the river banks along the entire river below the Morristown canyon. If the reach is aggradational the minimum first floor elevations should be evaluated to see if they need to be raised above those specified by the County's floodplain regulations. The reason for this is the uncertainty that is associated with sand bed rivers. The bed can aggrade or degrade significantly depending on inflowing sediment loads or channel avulsions. If a headcut moves up the river the downstream bed may aggrade by several feet where the sediment is deposited. The raising of the first floor elevations will help prevent damages from occurring due to potential future aggradation from headcuts along the Hassayampa River.

2) **Mining operations should be allowed in the river corridor but should be regulated so as to not destabilize the river.**

The performance of the existing pits provides a basis to make recommendations regarding future mining operations along the river. From the data obtained after the 2010 flood event it appears that pits which are shallow (similar to the Hanson and CEMEX in channel pits) and approximately the width of the channel cause less erosion than deep narrow pits. Pits that are long and deep (20-40 ft) cause significant headcuts and it remains to be seen if they stabilize or continue to deepen and lengthen. The broad but relatively shallower CEMEX and Hanson pits resulted in channel lowering on the order of 3 – 4 feet (near the pits and between the pits) while the much deeper Pioneer pit (approx 30-35 ft) resulted in a headcut of approximately 12 feet near the pit. A headcut of 3 – 4 feet can more easily be filled by channel transport and a new equilibrium reached than a 12 foot deep headcut.

From the data collected to date, the controlling factor for headcuts on the Hassayampa appears to be the elevation difference from the upstream brink to the downstream brink of the pit. Based on the observed data for the single deep pit (the Pioneer pit) it appears that the headcut depth may be controlled by the elevation of the pit's outlet after tailcut erosion occurs. Thus the elevation of the final headcut of the Pioneer pit was only slightly higher than the final elevation of the outlet from the Pioneer pit. It appears that some slope continues to exist across the pit but it is much smaller than the original river channel slope. Whether this is a general occurrence with deep, long pits or whether it was only a coincidence for the Pioneer pit should be investigated further. Consequently a series of wide, deep but short, well spaced pits may also be possible if modeling shows they are feasible. It is recommended that the District continue their policy of sediment transport modeling to show no adverse impacts.

3) **Off-channel mining operations should be encouraged.**

Mines in the floodplain areas (outside the floodway) can be much deeper than mines in the floodway. If the pits are protected from encroachment by the river (i.e. bank protection and berms) there is little reason to limit their depths other than geotechnical stability and the danger of seepage failures. Deep mines in the overbank should be bermed to prevent water from entering the mines up to the 100 year flood.

GENERAL OBSERVATIONS AND RECOMMENDATIONS

The following limitations/guidelines should be strongly recommended and/or enforced by the County:

4) **Bridges and transportation corridors should not constrain the river to the narrowest possible width.**

   One of the most serious obstacles to the protection of the river's stability may be the 18 or so bridges planned to cross the river. It is imperative that these bridges not constrain the river to the smallest opening possible. One of the reasons for this is that once the bridges are in place development pressure tends to fill the areas between the bridges causing continuous constriction of the river. Based on the sand bed nature of the river, the channel needs to be a broad flow path where the river can move from side to side with relatively shallow flows. Given the depth of the sand bed along this reach of the Hassayampa River, headcuts that form will have almost no natural limitations. There is no modeling evidence to date that indicates that Hassayampa River is in danger of significant headcuts but observations of sand bed streams in the southern, southwestern and mid-western United States indicate that once headcutting begins the consequences can be extreme and very expensive to contain. See for example: Buchingham, et al (year unknown), Haigh (1987), Las Vegas (1999), Rhoads (1990), Papanicolaou, et al (2008) [loess soils], Haynes and Huckell (1986), etc.)[3].

   If the river is constrained by bridges that are too narrow the constriction may cause a regime shift in the river. This regime shift moves the flow from a wide shallow flow to a narrow deep flow and would cause massive amounts of erosion in a sand bed channel. This regime shift normally creates a head cut that could move up river to the canyon area near Morristown or beyond.

   The formation of a headcut would cause two problems. The first problem is the lowering of the channel in the upstream reaches which requires the construction of grade control structures and bank protection not only on the river but on all of the tributaries about the headcut. The second problem is the deposition of all the sediment that is removed by the headcut at some distance downstream of the headcut. This deposited sediment would create major problems in the lower river (from the end of the constriction downstream - at a minimum from about I-10 to the Gila River). This deposition would require the raising of bridges, levees, and other related infrastructure. Further it would extend the floodplain (and possibly floodway) into areas that are not currently within the 100 year floodplain.

---

[3] A tour of the Santa Cruz River near Tucson is very instructive in the potential for headcutting on southwestern rivers. A 30 ft headcut moved approximately 35 miles up the river (Hayes and Huckell 1986) and another from the Greene Canal cutoff (probably 20 ft deep) is currently near Redrock moving upstream towards Tucson.

The I-10 bridges appear to be of adequate length to allow the river room to move and do not appear to have over constrained the river. Bridges approximately the length of the I-10 bridges should be considered as a minimum for use on the river unless further analysis indicates that shorter bridges are adequate. Each bridge should be analyzed individually but any recommended lengths that are significantly shorter than the I-10 spans should be carefully analyzed. The analysis for bridge lengths should not focus on a single bridge location but should, as an option, include all existing and proposed bridges from the Gila River to the Morristown Canyon. This analysis should include sediment transport and scour analysis in addition to floodplain hydraulics. An encroachment analysis is currently being performed by Stantec for the District and their recommendations should be referenced in any future analysis.

The evaluation of bridge length for a particular location also needs to include an economic analysis of all cost factors relating to the particular crossing. These include: a) the cost of longer approach embankment and roadway as the bridge length decreases, b) increased height of columns and embankment and wider approach footprint with water surface increase as bridge length decreases, c) increased erosion protection and foundation cost with velocity increases due to channel restriction, d) easement costs for the greater inundation potential, and e) increased mitigation costs due to larger environmental impacts from longer and wider approach embankments.

5) **Floodplain encroachment can probably be allowed in the non-floodway portions of the floodplain.**

Given the wide shallow floodplain in most areas, the floodplains can likely be safely developed as long as erosion protection is supplied and toe downs are used that will protect against normal scour as well as potential head cutting from mining operations or bridge constrictions. The constraints discussed in the next section regarding floodway encroachments are, however; extremely important and must be considered with any encroachment into the river's floodplain. Additional work is being performed by Stantec to determine how much encroachment is acceptable but any significant encroachment into the floodplain/floodway should be discouraged pending a careful sediment transport and river stability analysis.

The evaluation of floodplain encroachment should also include an economic evaluation of the incremental cost of fill and erosion protection per acre of land reclaimed vs. the incremental profit due to additional developable land. The cost of erosion protection should include life-cycle costs for maintenance over the life of the project, reduced to present value. It is essential to illuminate the true cost of reclaiming land from the floodplain since these long-term costs will eventually be borne by homeowners or taxpayers at large once the developer is gone.

Minimum toe downs for structures and bank protection should probably be significantly greater than the minimums normally used along the gravel and cobble bed rivers in Maricopa County. This increase in toe down is necessary to account for potential channel lowering due to mining and the additional potential scour due to the sand bed. Any banks that are constructed along the floodway line or that will potentially be subject to flood flows should be protected against erosion that will undoubtedly occur due to the sandy and extremely erodible nature of the floodplain. Bedforms should also be considered in any toe down calculations for the river. The District's most current hydraulics design manual (2010 Draft Drainage Design Manual, Hydraulics - available on their website) should be carefully followed in any performing any design work for the river.

The minimum elevation for development should possibly be raised above the minimum requirements since the river is possibly depositional in most of the reach above Jackrabbit Wash as discussed earlier in this document.

6) **Floodway encroachment should be tightly restricted and channelization of the river highly discouraged if allowed at all.**

It is our opinion based on field visits, a review of the impacts of sand and gravel mining, and other studies that have been performed that the encroachment into the Hassayampa River floodway by channelization should be avoided if possible. This is, of course, an ideal situation. Encroachments into the floodway must allow the river to retain its shallow broad flow pattern or serious erosion will result. The allowable width is being further investigated by Stantec under another contract for the District and their study should be followed. The narrowing of the floodway could result in natural channelization and down cutting of the river channel in addition to the artificial narrowing of the floodway. This could initiate headcuts that could move up the river to the rock outcrops near Morristown. The development of headcuts would result in major amounts of sediment being removed from the river and transported downstream towards the Gila River. (For an excellent case study see the Las Vegas Wash history[4]. [Las Vegas 1999]) The deposition of sediment in the lower reaches of the Hassayampa River would increase flooding and imperil existing infrastructure in the area. The head cutting,

---

[4] A good summary of the problems faced at Las Vegas Wash in contained in the document "Review of Headcut and Tailcut Methodologies" developed by R2D for the District in November 2010 (p 4-5). In summary a problem that may have been correctable for about $70,000 was left to advance and the Southern Nevada Water Authority will spend $110 million through 2015. It is estimated that it will cost at least $140 million (as of 2005) to just stabilize the wash in its current location and depth. The marina on Lake Mead at the wash outlet had to be moved due to the deposition of the sediment eroded from the wash. The Las Vegas Wash problem is in part due to the introduction of clear water flows from the waste water treatment plant (WWTP) approximately 9 miles above Lake Mead. A problem with clear water discharges from waste water treatment plants could occur on the Hassayampa if large WWTP discharges are planned. At this time the release of clear water into the Hassayampa River channel is not expected to be a problem. It is expected that most WWTP discharges will be utilized for irrigation and little will be discharged into the channel. If large discharges are planned and areas with cemented layers that might impact infiltration are found the impact should be analyzed to identify problems prior to construction of large waste water facilities.

if it starts, would extend up all of the tributaries and result in the formation of gulleys and other significant erosion features. The erosion in the tributaries could endanger additional infrastructure and endanger homes and other constructed features in upland areas as the channels undercut currently stable banks. There may be some areas where encroachments could occur but significant modeling would be required to insure the encroachment did not cause problems both upstream and downstream.

It is also very important that development in the form of residential and commercial development, bridge construction, pipelines, electrical towers, and etc. do not impact sediment transport in the river. The disruption of sediment transport will have long term negative impacts on the river and may cost tens of millions of dollars to correct or contain the problems.

7) **Recreation potential should be protected and developed for all users.**

The river corridor is currently used extensively by ATV's (all terrain vehicles) and off highway vehicles (OHV's). This use could be continued given the wide floodplain and some pits could be reclaimed to allow their use for ATV climbing and trail riding. This would require that some of the final slopes of the pit walls or waste piles to be left with slopes steeper than what those normally required by the District. The slopes should not be so steep as to be unstable or dangerous but steep enough and variable enough to provide some challenge for ATV riders. This recreational use would need to be acceptable to the land owners and the County.

The river corridor offers excellent opportunities for equestrian trails, wildlife access, nature areas, and foot trails. Paved trails should not be in areas where the river is actively scouring or depositing and should possibly be restricted to the portions of the corridor along the boundary of the floodway or developed corridor. A wide floodway corridor would allow ATVs, hiking, wildlife and equestrian users the ability to utilize the corridor but still have sufficient separation so as to prevent conflict between the various uses.

The floodway area could be utilized for developed parks but this is not recommended due to the high sediment load and the tendency of the river to change course within the floodway. Deflection/protection works could be installed for small to intermediate floods to reduce damage to the investments in park infrastructure when the river changes flow paths within the floodway but significant damages should be expected for developed parks within the existing floodway.

References

Buchingham, S.E., Whitney, J.W., Glancy, P.A. and Ehrenberg, A. (unknown date). "Recent Flooding and Environmental Change in Las Vegas Wash, USGS, Web Address:

http://gec.cr.usgs.gov/info/sw/alluvial/lvwash.html

Derrick, David L. (2010). Personal Communication, US Army Corps of Engineers, Engineering Research and Development Center, Vicksburg, Mississippi.

Drainage Design Manual for Maricopa County, Arizona, Hydraulics (Draft 2010).

Floodplain Regulations for Maricopa County, Flood Control District of Maricopa County, 2011, **http://www.fcd.maricopa.gov/Permitting/downloads/Floodplain_Reg_Book.pdf**

Haigh, Martin J. (1987). "Evolution of an Anthropogenic Desert Gully System", Erosion, Transport and Deposition Processes, Proceedings of the Jerusalem Workshop, March-April 1987, IAHS Publ No. 189, 1990.

Haynes, C.V., Huckell, B.B. (1986). Sedimentary Successions of the Prehistoric Santa Cruz River, Tucson, Arizona, Arizona Geologic Survey Open File Report 86-15, Arizona Geological Survey, Tucson, AZ.

Jacobs Engineering (2008). Final Design of the Interim Wickenburg Bypass, ADOT.

Las Vegas Wash Coordination Committee, (1999). Las Vegas Wash Comprehensive Adaptive Management Plan, Web Address: http://www.lvwash.org/html/resources_library_lvwcamp.html

Panpanicolaou, Thanos; Wilson, Christopher; Dermisis, Dimitrios; Elhakeem, Mohamed; and Thomas, John (2008). The Effects of Headcut and Knickpoint Propogation on Bridges in Iowa, Report TR-541, Iowa Department of Transportation, Iowa Highway Research Board. Focus in on Loess Soils. Web Link: http://www.iowadot.gov/operationsresearch/reports/reports_pdf/hr_and_tr/reports/TR-541%20Final%20-%20T.%20Papanicolaou.pdf

Rhoads, Bruce L. (1990). "The Impact of Stream Channelization on the Geomorphic Stability of an Arid-region River", National Geographic Research 6(2):157-177, Web Address: https://netfiles.uiuc.edu/brhoads/www/rhoads1990.pdf

(R2D) River Research & Design, Inc. (2011). Comparison of Sediment Transport Models for the Lower Hassayampa River, Prepared for the Flood Control District of Maricopa County.

The CK Group (2007). Access Control and Area Corridor Study for Patton Road and Jomax Road (299th Avenue to Tillman Boulevard). Appendix H – Hassyampa River CAR. Prepared for the Maricopa County Department of Transportation