ESTABLISHING A MULTIFUNCTIONAL GPS BASE STATION
FOR
SURVEY AND RESOURCE GRADE APPLICATIONS

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I. Abstract

The overall purpose of this paper is to impart knowledge to those who are considering the construction and maintenance of *Multifunctional Global Positioning System Base Stations* (MGBS). There are many approaches that must be weighed as each decision carries unique ramifications. This paper will endeavor to convey ideas regarding areas the *Las Vegas Valley Water District* (LVVWD or District) explored in its efforts to find the best GPS solution for the unique environmental and topographical conditions that exist in the Las Vegas valley.

Our initial MGBS solutions were based upon the technology and resources available during the early part of 1996. However, this paper attempts to share the ingenuity employed to solve aberrant problems that subsequently surfaced along the ever-evolving path of technological change. An ancillary purpose of this paper strives to impart information that incorporates future technologies when appropriate. It is common knowledge to those associated with wireless technology that the telecommunications industry is currently changing at a rapid pace.

A portion of the areas covered within this paper consist of, but are not necessarily limited to; benefit, partnering, precise positioning and the HARN, data formats, wired and variations of wireless communication solutions, digi-repeater arrays, antennae radiation patterns and specific applications, primary and secondary photovoltaic power supplies, geological substructure and subsidence, property acquisition, data liability, as well as some of the problems encountered whether solved or subsequently avoided.

II. Background

The Las Vegas Valley Water District's base station has been in operation since March of 1996. Our datashare commenced to offer Static information on the *World Wide Web* (www) beginning in October of 1997. Over the years the District has had many opportunities to delve into new areas, explore alternatives and work with new technology, as well as apply current technology to new applications. Our team of professionals has sifted out applications to technology that didn't meet the specific needs and/or match local conditions for various reasons.

Perhaps an overview of the District's orientation to the public is appropriate and beneficial. Our organization established this system to meet the needs and requirements of the Engineering Department’s Design, Construction and AM/FM/GIS Divisions. In addition, the MGBS supports the requirements of many other departments and divisions within the District, the *Southern Nevada Water Authority* (SNWA) and the *Southern Nevada Water System* (SNWS). All of these branches of the District were created by various acts of the Nevada Legislature. As such, the District is known as a quasi-municipal organization. These branches employ a cumulative total of approximately 1,000 personnel performing various functions related to maintaining a safe and reliable water system.

Las Vegas has been growing at a rate of about 80,000 new residents per year. The preceding growth rate can be better understood in stating that the rate of new residents is mathematically analogous with a family of five arriving to this city approximately every one-half hour. Las Vegas' current resident population is approaching 1.2 million. Tourism is yet another challenge to our production and water systems. This city entertains approximately 32 million visitors a year at visiting rates that at times seem literally circadian.

Until just recently our operations were funded solely by *rate payers* (customers). The District has recently become the beneficiary to a portion of a one-quarter percent county imposed sales tax. This tax is designed to support the costs of additional regional water facility infrastructure. This infrastructure is necessary to provide system reliability designed to meet the current and future needs of the valley’s water demands.

The preceding message can be translated to say that our main function at the District is to serve the needs of our existing and future customers. In our efficiency-driven effort to increase the system expansion and effectiveness; this District is pleased to be able to share GPS data either by means of the Internet and/or wireless *Real-Time Kinematic* (RTK) transmission. Sharing District information is possible if it does not inconvenience current systems and/or impede service commitments.

Additionally noteworthy is the fact that offering this data creates concern with potential uses and/or misuses of these GPS systems. It is clearly evident that there exists an inability to control the use of information after it is shared and leaves our repository. The best anyone can do is to troubleshoot these systems. Additionally, care should be taken to elevate GPS knowledge in an effort to better orient new users with potential problems related to pushing the limits of GPS technology. Of primary concern is the subsequent use of RTK technology. As education chairman for the Southern Chapter of the Nevada Association of Land Surveyors and adjunct instructor at one of the local community colleges, the author is dedicated to promoting GPS education.

Scope of Understanding: This paper assumes that the GPS technician and/or professional is somewhat familiar with standard GPS equipment inclusive of, but not limited to; Static related and RTK operations and equipment.

III. Why Construct Multifunctional GPS Base Stations?

There are many reasons a community or organization may wish to establish a MGBS. The reasons are somewhat universal for various applications. However, some are specific applications that depend upon the technique and equipment available, as well as budgetary allowances.

A. General Benefits

Perhaps the best benefit to the private sector in erecting MGBSs is the elimination of theft of personal remote base equipment. Consultants operating GPS equipment in the Las Vegas valley have become victims to theft approximately three times during the last two years alone. In recognition of the preceding, MGBSs allow a release of concern regarding remote base theft and users save the hourly fees spent paying non-technical staff to guard that equipment.

B. Real-Time Kinematics Benefits

Efficiency: One of the more beneficial considerations surrounding the erection of MGBSs is that users will be afforded the opportunity to capitalize upon saving approximately 1.5 crew-hours per day. This could apply to multiple crews as well. This is because crews don't have to set up and subsequently take down a mobile-style GPS base station each day. The result is either a proportionate savings to clients, higher productivity, or a combination of both. An additional benefit is realized within competitive proposals and a higher overall profit margin.

Seamless Coordinates: Another benefit to cities, counties and other agencies is that all of the subsequent geographic coordinates are now on one seamless system limited spatially by the statistical accuracy of the data collected, compiled and analyzed, as well as the technique used to acquire this information.

High Accuracy Reference Network: Choosing to adjust the MGBS using the *National Geodetic Survey's* (NGS) *High Accuracy Reference Network* (HARN) monuments will result with a bettered repeatability and higher accuracy using RTK as most states' NGS HARN adjustment results are now achieving a 2-cm full-network positional accuracy (2 Sigma).

The HARN accuracy provides 2-cm reliability on a statewide network basis in both the horizontal and ellipsoidal components. This is exceptional for many purposes despite the fact that it can exceed most needs for building GIS databases. (For other national HARN benefits see the NGS homesite http://www.ngs.noaa.gov). Additionally, as eluded to above, previously local "*Job Coordinate*" (JC) systems can now become seamless with minor ground projection variations. The difference to the preceding statement with that listed under the "*Seamless Coordinate*" section, above, is that the HARN system is national in its spatial integrity rather than a local wide-area system.

Incidentally, regarding the HARN, the District is proud to announce that our MGBS was included as a *Central Temporary Continuously Operating Reference Station* (CTCORS) for this year's Nevada GPS HARN Re-observation (GPS 1356). This consisted of compiling approximately 40 days of continuous 24-hour 30-second synchronized Rinex data sets. The station will subsequently have an official HARN grade position. The final position for our MGBS is scheduled for release by the NGS prior to the coming millennium. Interested person's considering the erection of MGBSs for which a states have not yet performed their second HARN observation should put efforts in motion to take advantage of that partnering solution.

Partnering: If cities, counties, and agencies, etc., coordinate their efforts by working together to build networks and coverage areas, they can benefit from a reduction in potential duplication of resources and associated expenditures.

Of additional benefit to partnering is that the GPS survey grade equipment formerly used as a base station can be donated to promote extended area network coverage. If that is not an option deemed feasible to the corporation's board of directors, direct additional benefits are also realized by subsequently employing former base station equipment as yet another rover. This increases the ability to meet higher survey production demands.

C. Static and Static Related Technology and Benefits

Sharing base station data is a smart idea. Sharing is easier on the provider by establishing an Internet link to access GPS data.

Low or No Cost Employees: Consider these MGBSs as one more receiver in the field with a HARN or local control position at generally no direct cost to the user. While for good reason (e.g. maintenance, system costs, etc.) some choose to charge for the data, users save the cost of paying another employee to gain network strength and ultimately vectors. Quality vectors in most cases strengthen the geometry of the Static network, provide checks to constrained control, and assist in detecting blunders in antenna heights, etc.

If users choose Trimble's© *Universal Reference System* (URS©) software, providers can make information available in many formats. Some of the formats the District chose to use consist of *Receiver Independent Exchange Format* (Rinex), DAT and SSF (DAT and SSF are Trimble© specific acronyms). These Rinex and DAT formats are most convenient for use within Static technology systems. With URS©, users can establish a *"Roll Over" Time* (ROT) and store the asynchronous data over a specified time period. The ROT is useful for minimizing file storage by overwriting older stored data sets at variable time intervals.

The District currently offers Static data on a full-year basis with a synchronization epoch rate of 5 seconds. Each file is extracted and stored in 1-hour file coverages. It was envisioned that a year's worth of data would be useful for scientific studies. However, the District plans to change to a more "practical" 60-day data storage system. Establishing a repository and determining the proper amount of data storage is an example of the learning curve associated with the process of establishing MGBSs. Upon revision of the data storage guidelines, the District will then offer older data on an as-needed basis. This older information will be extracted from a back-up tape drive system.

The District encourages interested parties to please visit this website and comment using the available e-mail hotlink provided at the bottom of the site.
http://www.lvvwd.com/data_share/gps.html

D. Resource Grade Benefits
The third file format shared within our Internet site is the SSF file. (SSF is a Trimble© specific acronym). This file is most useful for users with resource grade applications that store *Course Acquisition* (C/A) data and then desire to process it later for higher positional accuracy. Depending upon the software owned these DAT and Rinex files are also useful for the purpose of correcting C/A data sets. The amount of data and file coverage for this purpose is currently the same as that for the Static related data share.

Real-Time Benefits: The District has also been experimenting with transmission of the *Radio Technical Commission for Maritime, Special Committee No. 104* (RTCM-104) condensed message to resource grade receivers that recognize the Trimble© condensed message. Not all GPS receivers can employ this condensed message (see manufacturer specifications).

E. Scientific Studies and Related Research Benefits
This category could fall within the Static related category. However, there is so much activity and related benefit within this particular area that is deserves separate attention and consideration. The scientific community has been a boon to land surveyors and *Geographic Information Systems* (GIS) specialists, as well as to others.

SCIGN: One specific example is the *Southern California Integrated GPS Network* (SCIGN). SCIGN is comprised of a group of scientists, geologists, oceanographers, engineers, educators and land surveyors, as well as other professionals. This is an excellent example of partnering wherein the associated players benefit from the establishment of *Continuously Operating Reference Stations* (CORS) and related GPS data. http://www.scign.org

SCIGN is comprised, in part, by members of the *National Aeronautical and Space Administration* (NASA) , as well as NASAs *Jet Propulsion Laboratory* (JPL), the *United States Geological Survey* (USGS), the *Southern California Earthquake Center* (SCEC), *Scripps Institution of Oceanography* (SIO), the *National Oceanic and Atmospheric Administration* (NOAA), as well as others. There are also representatives of SCIGN from various universities throughout the United States. These scientists are studying earthquakes, tectonic activity, and space technology, etc. These studies allow integrated spatial accuracy using the benefit and aide of full-wave dual frequency GPS data sets.

Funding Advantages: This partnership is so important to land surveyors because among other advantages, it can provide an opportunity to share MGBS expenses with other funding sources. Examples of SCIGN’s funding sources are representative of the Keck Foundation, NASA, USGS and the *National Science Foundation* (NSF). Local communities that can partner with these organizations can benefit tremendously from that relationship. Each participant in turn benefits because no single organization bears the full cost for any single system. Also, each participant has an opportunity to show community support. The placement of MGBSs can be co-located in areas that are of mutual benefit to all while in most cases continue to maintain scientific initiatives and purposes.

Potential scientific research partnering areas may include, but are not necessarily limited to: earthquake related studies; tectonic and quaternary faulting measurements; photogrammetry; subsidence, load induced deformation and related geological studies; oceanic, riparian and tidal equipotential studies, as well as and special elements of space exploration. The list of beneficiaries grows seemingly exponentially with time. Land surveyors and geodesists everywhere should welcome and embrace the potential for these relationships.

IV. Financial Considerations, Requirements and Justifications

A. Multifunctional Base Station Equipment

There are many advancements and equipment categories to consider. What follows is a representation of the equipment the District considered, further developed or implemented.

Basic Equipment: Rhudamentary requirements to erect an MGBS include a dual frequency (L1/L2 – and soon L5) antenna, an appropriate GPS receiver, and some cabling. For high-grade applications providers should consider the benefits of Dorne-Margolin© *Choke Ring* antennae. Trimble© offers a certified version of this choke ring antenna that comes with a certification denoting the calibrated accuracy of the antenna's performance.

Interested parties can also order a Radome cover that is mounted upon Choke Ring antennae such that it will deflect debris, water and other nuisances that could otherwise enter the anechoic chambers and thus impede signal reception. Additional attention is offered for users to inquire about the functionality of a "*Quad-port*" (QP) option for the Trimble© 4000 SSi. This will allow more flexibility when transmitting multiple Real-Time differential correction formats and/or data types.

Wired Connections: In addition to the preceding information, considerations for hardwire data transmission may include RG58/U coaxial cabling and/or Heliax "*Low Loss*" (LL) cabling. Consideration of a fully dedicated computer for processing, storage and networking to an Internet server is also important.

Simultaneous Real-Time Transmissions: When employing combined data type transmissions for RTK and RTCM-104 simultaneously, consideration of an applicable antenna array is desirous. If transferring RTK and/or RTCM data from the URS© processor to an alternate location is required, the use of a short-haul modem helps to alleviate wireless *Near Field Interference* (NFI) and/or other inter-modulation problems. The short-haul modem may require a standard audio leased 3002 data circuit line (so called "*Dry Pair*"). For more information see the *Noteworthy Problems and Potential Solutions* section of this paper.

Primary Power Supply: Organizations that intend to use *Alternating Current* (AC) as a primary power supply should consider the benefits of surge protection. Costs to construct power transmissions to remote areas are expensive.

Back-up Battery System: Organizations or partners desirous of creating a community system, for which many will come to rely upon the services provided thereof, should consider a back-up battery system in the event of a power outage. The back-up power supply not only assists the field personnel with continuous RTK operation, it also assures compliance with, and continuity during data storage for subsequent Static applications. The latter suggestion is not only beneficial when contemplating an MGBS expenditure, it is also one of the requests of the NGS when attempting to incorporate the station and related data within the NGS CORS array.
http://www.ngs.noaa.gov/CORS/Site_selec_crit.html

Digi-Repeater Array: If RTK coverage is needed for permanent sites, a digi-repeater array is required. However, be aware that not only are there limitations in projecting an RTK baseline from a base station, there are also limitations in data packet bit transmission. For more information see the *"Noteworthy Problems and Potential Solutions"* section of this paper. Current *Ultra High Frequency* (UHF) RTK transmissions are not intended to be bi-directional or *Duplex.* (Duplex refers to using two frequencies for repeating). These systems are generally *Simplex.* (Simplex utilizes a single frequency.)

Experience and an understanding of radio technology has indicated that using a vehicle as a digi-repeater provides an excellent advantage. This is because a vehicle's metal and mass can act as a very dependable and efficient ground plane. Conversely, a vehicle can add multipath to the rover/Static survey. The digi-repeater benefit continues in that a vehicle is also mobile. Users can drive to areas with good reception near the project watching the data indicator of the radio modem. When the indicator shows adequate reception, stop, park and lock the vehicle if necessary. Then set off on foot to the project site with a GPS rover.

Helium Balloons and Digi-Repeaters: For users that are located in areas that exhibit foliage, consideration of the purchase of a helium balloon complete with a secure non-conducting tether should better productivity. This system should preferably be anchored to a vehicle for security and/or stability. The average digi-repeater equipment operation requires about five pounds of lift. Said lift equates to a requirement of approximately 220 cubic feet of helium.

One particular balloon, which meets this requirement, stands about 5 feet tall and it is tear shaped in design for additional stability during mild winds. Keep in mind that the helium requirement can vary, as this is a function of barometric pressure, humidity, and wind speed, etc. The preceding volume requirement noted should be ideal to lift a digi-repeater, 8-hour battery, a small Omni-directional antenna and a short antenna to digi-repeater (modem) cabling system for use under fairly stable weather conditions.

This particular digi-repeater application usually doesn't necessarily require high-watt repeating abilities due to the superb line-of-sight advantages with height. According to the language contained within applicable FCC regulations, under most scenarios there is a height allowance of up to 100 feet above the ground without taking note of any further wattage and/or licensing restrictions in most cases.

Care should be taken as to avoid obstructing aircraft runway protection zones. (See applicable FAA restrictions.) It is fairly evident that care should also be taken to ensure that users do not obstruct any overhead obstacle or put the helium digi-repeater system in harms way during an electrical storm. Interested parties should review FCC restrictions to height associated with transmission when exceeding 100 feet. (For more information see Title 47, Code of Federal Regulations, Part 90, Sections 307, and the related charts found in Section 309.)
http://www.access.gpo.gov/nara/cfr/waisidx_98/47cfr90_98.html

The increased efficiency in dense foliage may justify the cost and extra effort using the helium balloon system. Coverage may vary depending upon a number of factors. Photogrammetrists are also using this type of system for *Close-Range Photogrammetry* (CRP). The District is in the process of designing this digi-repeater system. However, it may not actually be constructed and/or deployed due to the District's mountain digi-repeater coverage. See the section entitled "*Digi-Repeater Array*" located within this paper for additional information.

Lightning Protection: Depending upon local climate and environmental conditions, users may want to consider lightning arrestors and/or associated grounding rods for electrical storm protection. In actuality, after considering the costs involved in losing a digi-repeater array or other associated equipment, grounding would be difficult not to justify. Solid grounding is a requirement for operating electrical equipment pursuant to code compliance. If the system lost service under electrical storm, surveys cease, time is lost, equipment is destroyed, and an overall inconvenience becomes evident to all concerned. As this paper will reveal, electrical technician fees and time surrounding trouble-shooting can be somewhat expensive.

Amplification: Organizations that go to the trouble of establishing an MGBS should also find it important to ensure real-time coverage. High volume wattage is not the most important factor in obtaining coverage. Proper wattage is desirable to limit expenditures, complaints due to extended range considerations, as well as to reduce the potential for local inter-modulation. In most cases MGBSs require wattage above and beyond most one-half to 2-watt radio capabilities. The District chose a 500 *milli-Watt* (mW) input and a 100 *watt* (W) output amplifier.

The radio modem output dictated the amplifier input power and our antenna array, in recognition of our allowable *Effective Radiated Power* (ERP) as listed on our FCC license, controlled the wattage output selection. ERPs or other license specifications can be modified. However, the process takes a considerable amount of time. (For more information regarding license changes see CFR 47, 90.135.)
http://www.access.gpo.gov/nara/cfr/waisidx_98/47cfr90_98.html

Secondary Power Supply: This paper has already conveyed information pertaining to the primary power supply. However, users may be required to transform 110 *Volts* (V) to 12V. A power supply is generally a relatively inexpensive item. However, some models can be quite elaborate adding volt and current meters, as well as other indicators. These added features tend to increase the expense for a power supply.

Photovoltaic Power Systems: *Solar Electric Systems* (SES or Photovoltaic) use *Direct Current* (DC) solar panels. An SES can either be installed at digi-repeater and/or MGBS sites. Cyclic and/or seasonal solar exposure and related cloud coverage should dictate the amount of back-up batteries required to operate during periods of solar cover. Solar exposure will also dictate the required amount and type of solar panels.

Photovoltaic system photocell expenses are generally proportionate to the amount of power needed to support the radio needs. There are also a few additional small electronic devices that require power at digi-repeater sites. A somewhat advanced photovoltaic system might also include meters, line ties, an inverter (DC to AC), as well as charge controls to govern energy transferred to the back-up batteries.

Depending upon the current requirements, interested parties may wish to incorporate a remote system to turn off the digi-repeater during periods when the system is not needed. Caution is herein extended because the last suggestion should be coordinated with other users to ensure that the system is not turned off when it is truly needed.

Fuse Compartment: Not unlike surge protection, consideration of a fuse compartment for the added protection of various circuitry and devices is a wise choice. A number of manufacturers incorporate fuses into their products. However, those who choose to protect the equipment within a cabinet using an alternate fuse compartment will benefit by not having to dismount and/or remove individual equipment and related shielding covers to change internal equipment fuses.

Equipment Cabinet: Establishing a permanent transmission or digi-repeater point generally requires a sturdy cabinet. The District chose metal cabinets. It is the opinion of our professionals that electrical circuitry should be grounded. The District's metal cabinets are also equipped with gaskets for keeping undesired moisture out. A cabinet is also beneficial towards extending the product life of the equipment mounted within. Additionally, the use of a cabinet will provide protection against outages caused by someone coming too close to otherwise unprotected equipment and accidentally bumping a plug, turning off a device or crushing and/or damaging components.

Environmental Conditioning: In areas where extreme temperatures can have an effect on equipment, consideration of *Heating, Ventilation and Air-Conditioning* (HVAC) systems is crucial. Sensitive radio modems and other electronic equipment are adversely effected during extreme weather conditions. See the appropriate manufacturer's guide(s) for specifications about operating temperature ranges.

B. Dual Frequency GPS (L1/L2) Antenna Placement

There are some important factors to consider when establishing a permanent antenna locality. Some of these issues are explained herein. Due to the costs involved to purchase the equipment to erect MGBSs, considerations for the antenna structural support must be paramount. A somewhat less important but noteworthy factor is consideration of the underlying geoidal composition. However, if a need for a MGBS is identified as feasible, undesirable geoidal conditions can be overcome with a correlated residual model for Static and/or calibration procedure for use with RTK.

Geological Substructure and Subsidence: Subterranean soil conditions and geological substructure must be considered and scrutinized. Determining favorable conditions may add considerable costs to the construction of the MGBS in order to better the stability and positional integrity of the antenna. While in some cases substructural displacement may be beneficial for the scientific community to detect movement, these stations are usually limited in benefits by providing preliminary episodic earthquake, faulting and subsidence warnings, for instance.

In some cases surface movement may also help denote potential soil saturation conditions or the potential for other surface disasters to come. However, in almost all cases, surface movement for land surveyors and geodesists renders a GPS base station and its data somewhat useless. The preceding is not necessarily true if an *Epoch Date* is incorporated within the survey plat or enough data has been collected to model and calculate land movement vs. time. The preceding relationship is formerly called a *Velocity Rate* (VR).

Particular areas within California, for instance, are subject to earthquakes and major, as well as minor faulting. In this locality the Pacific plate is moving with respect to the North American plate. It is my understanding that Dr. Dennis Milbert, NGS, formulated the first model to attempt to measure various conditions of VRs on a continental basis. It is also my understanding that this model is formally called the *Horizontal Time Dependent Positioning* (HTDP) system.

Others have subsequently improved HTDP modeling in areas that are of prime importance to understanding their community's variable VRs and related potential catastrophic exposure. However, HTDP is of the utmost importance to land surveyors in relating older surveys to new tectonic related conditions and subsequently new survey measurements.

Based upon the District’s field measurements and the following Interferometric Synthetic Aperture Radar (InSAR) data, it appears evident that this valley is somewhat “well behaved” as regards VR. However, Las Vegas has experienced earthquake activity during the *Load Enduced Deformation* (LED) that occurred with the introduction of additional Colorado River water into Lake Mead via Hoover Dam (A.k.a. Boulder Dam). Past LED evidenced earthquakes have approached a level of 6.0 on the Richter Scale at various stages during the period following final completion of the dam.

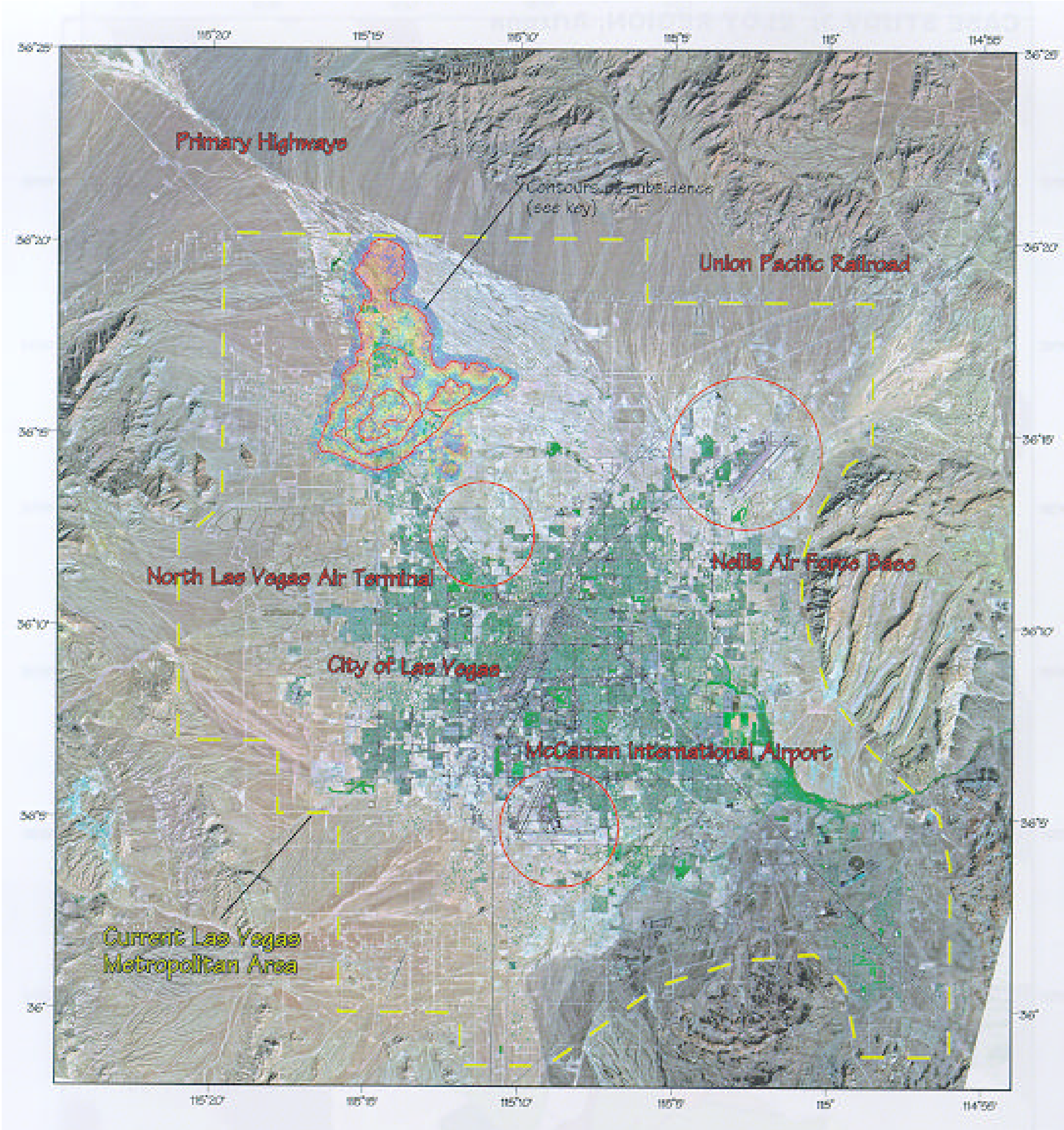
Part of the reason to include InSAR information was also to take note of the fact that favorable locations for MGBS antennae, in most cases, are located in bedrock or rock outcroppings. The District's MGBS is mounted upon a structural element of our two-story building. Our building is situated upon a caliche layer of considerable depth. Caliche is a form of calcium carbonate limestone that has twice the pressure rating of most high-grade concrete. Additionally, caliche is so hard that it must be blasted with explosives to facilitate construction-grading procedures.

Interferometric Synthetic Aperture Radar: The picture below is called an *Interferometric Synthetic Aperture Radar* (InSAR) precision electromagnetic survey. It specifically covers the Las Vegas valley and was prepared by Nygil Press Associates. (For more information on InSAR and NPA see their homesite www.npagroup.co.uk or contact ren@npagroup.co.uk.) The particular survey shown herein spans two "snapshots" taken on April 6, 1993 against April 18, 1996. The subsidence represents a total of about three and one-half inches (3.5") during this period. The last ERS satellite snapshot coincides with the commencement of our MGBS data (3/96). The InSAR survey confirms the District’s Static GPS findings. The results indicate stability at our base station for that period and each technique supports the results of the other.

The preceding can be restated by stating that movement at our MGBS is either at a level that can’t be fully detected and/or the movement is at a level that is not significantly adverse for our uses. The data indicates millimeter differences between subsequent independent surveys. This discrepancy is attributed to either; daily solar attraction, potential seasonal water levels, HARN monumentation VRs, or a combination of any of these, and/or other unknown factors.

As evidenced from the InSAR photo below, the areas of subsidence are located in the northwest part of our valley and not in the central area where our MGBS is located. The contoured area in the northwest (so called *Fringes*) are the areas reported to have endured subsidence during this period. Each change in color represents a specific amount of elevation change. The overall color spectra indicate the total subsidence. InSAR technology is reported in accuracy at the sub-millimeter and/or millimeter level.

It was also noted within this particular InSAR study that minor faulting was evidence during this period near the center of the shown subsidence area. Evidence of this particular faulting



is apparently located in a northeast/southwest strike-slip direction.

INTERFEROGRAMMETRIC SYNTHETIC APERTURE RADAR DEPICTING SUBSIDENCE IN LAS VEGAS, NV COMPLIMENTS OF www.npagroup.co.uk

It appears common knowledge that our Earth is a living and breathing planet that is subject to seemingly constant change. Taking these factors into consideration prior to constructing an MGBS, in the author's opinion, constitutes a responsible approach during the performance of public service while providing protection for the provider's financial investment.

C. Ancillary Equipment
It is beneficial for those interested in establishing an MGPS to become familiar with other related equipment and adapters. Some of the following equipment can provide very effective solutions.

Spectrum Analyzer: The spectrum analyzer is very beneficial for testing radio transmissions. If for any reason it is suspected that a radio system is malfunctioning, this rather costly piece of equipment can help diagnose and solve that problem. Radio transmission problems may evidence themselves by virtue of a complainant's visit, phone call or formal letter. Keep in mind that once desired parties construct an MGBS, the transmission position is easily detected should the radio system propagate transmission (emission) violations. A spectrum analyzer can also double as a scanner. However, this is an expensive tool in the event that all that is really needed are the benefits of a hand held frequency scanner. However, spectrum analyzer systems can often be available for short-term rental use.

Real-Time Radio Reception Survey: The spectrum analyzer can assist in another important function informally called a *Radio Survey*. This survey will test *Receiver Signal Strength Indication* (RSSI) at specific positions within the intended wireless coverage area. This information is very important when both placing an MGBS and a digi-repeater location. In this latter capacity, the spectrum analyzer can detect *Radio Frequency* (RF) irregularities.

Terminal© or HyperTerminal© programs are also useful at times for detecting data packet interruptions. However, possibly the best method of detecting RF transmissions is trial and error using qualified telemetry personnel. This is an expensive method as telemetry, or frequency engineers, can charge fees upwards of $185.00 per-hour per-crew for their services. However, in many cases employing these technology specialists is a practical solution.

Hand Held Frequency Scanner: Another important tool is the hand held frequency scanner. Private UHF RTK frequencies are currently but separately licensed for both voice and data transmission on the same frequencies. Data users must yield to voice users. The scanner is very useful for checking various frequencies to find a private sector co-user frequency that is not currently being used by voice traffic. Scanners are relatively inexpensive; however, they can help offer protection from a subsequent fine when operating while voice users are transmitting.

Pre-scanning is a requirement for co-user frequency licensing and it is simply a good practice to avoid conflicts. Most radios are equipped with digi-squelch technology that in most cases shuts down radio transmission in the event that voice or other traffic is detected. Another new UHF radio feature is "*Call-Sign ID*" (CSID). This feature transmits the user-licensed call sign (e.g. WPKI603) on a prescribed time interval.

The CSID number provides sufficient information that allows a complainant to contact the responsible party by researching the CSID on the Internet. The "benefit" of being accessible to complainants is that both parties have an opportunity to work out difficulties before the FCC gets involved. http://gullfoss.fcc.gov:8080/cgi-bin/ws.exe/beta/genmen/index.hts

RF Cable Adapters: Another important piece of equipment that provides a solution when connecting various RF and GPS devices together consists of using cable adapters. These handy adapters consist of variations of male to female, female to male and also male/male, female/female connectors. The common types used for RF GPS connections are N, BNC, TNC, PL-259, Mini UHF and SMAs, for example. The ability to interface other pieces of equipment is often an advantage when configuring and utilizing various ancillary GPS equipment. It should be noted that adapters are sometimes a source of discontinuity in cabling and also have a tendency to degrade the impedance of the signal's pass. Regardless, these adapters can mean the difference between a good day at work or a potential budgetary drain.

Signal Attenuators: Attenuators are another important part of ancillary RTK radio equipment operation. These devices restrict the output of the radio, modem or other transmission device. This is beneficial for cutting the amplification of a 2-watt to a half-watt transmission, for instance. This particular example would require about 6-decibel (dB) of attenuation.

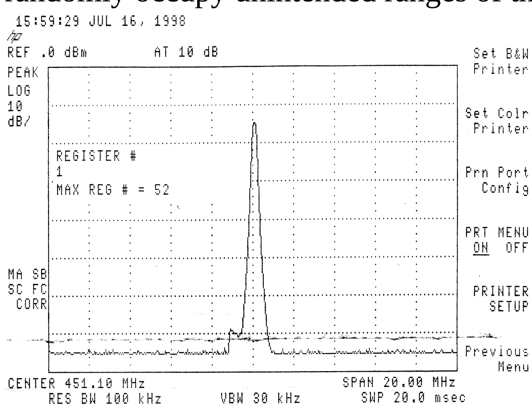
One primary reason for the use of signal attenuators in RTK transmission is to limit the wattage of a digi-repeater so as not to effect other users. This is done periodically to limit the coverage area of the digi-repeater. Covering *"shadowed"* areas is important. A shadowed area is a location, or locations that are otherwise obstructed from the MGBS or digi-repeater line-of-sight and/or optimal transmission coverage area.

Problems associated with high-watt digi-repeating can be related to poor signal to noise ratios, rover proximity to the GPS base station and data packet byte lengths, etc. The latter will be discussed under the "*Simultaneous RTCM-104 and CMR Real-Time Data Transmission*" section to follow. A good rule of thumb regarding attenuation is that each 3-dB reduces the radio output power about one-half the current power. In example, a 100-watt amplifier with a 3-dB attenuation reduces the output to approximately 50 watts in effect. Conversely however, a 3-dB gain in antenna design increases the output approximately twice the original level.

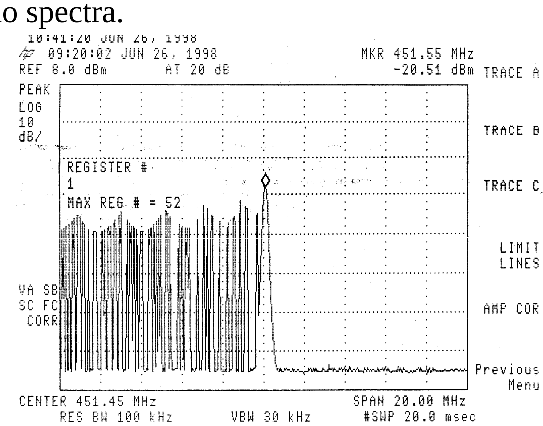
UHF Frequency Compliance and Shift Keying: It is my understanding that the most widely used form of RTK transmission in the United States is currently *Ultra High Frequency* (UHF). UHF licenses are predominantly issued at a 25-*kilohertz* (kHz) spacing. The actual performance of the radio may be a function of the data speeds available and the radios' internal transmission programming, among other considerations. Examples of types of data transmission keying are *Gaussian Minimum Shift Keying* (GMSK), *Amplitude Shift Keying* (ASK), *Frequency Shift Keying* (FSK), *Phase Shift Keying* (PSK) and *Bi-Phase Shift Keying* (BPSK) in quadrature, etc.

Continuing compliance related issues; it is likely that the UHF license only allows 12.5 kilohertz of side band on either side of the center (issued/licensed) frequency regardless of the particular shift keying the radio modem employs. Any transmissions outside the side band, called "*splatter*," are considered a violation of FCC rules.

Irregularities in these cases are therefore subject to fines and a potential loss of license for repeat performances. These "transmissions" could be more appropriately considered as *emissions* because they serve no useful communication purpose. Additionally emissions denote harm. This is certainly the case as concerns other users because the emissions randomly occupy unintended ranges of the radio spectra.



CLEAN TRANSMISSION



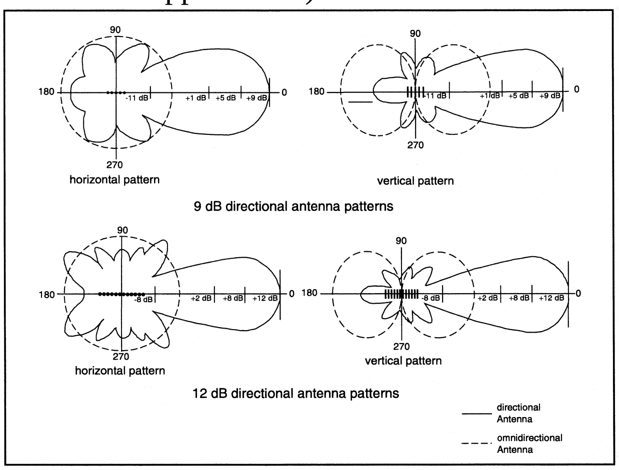
"SPLATTERED" TRANSMISSION

As the graphics so evidence, the spectrum analyzer is an excellent tool for detecting RF splatter. However, as stated earlier within this paper, the *Spectrum Analyzer* (SA) is an expensive piece of equipment if used solely for scanning and transmission screening purposes. The SA is also capable of performing a wide range of electronics related tests and functions.

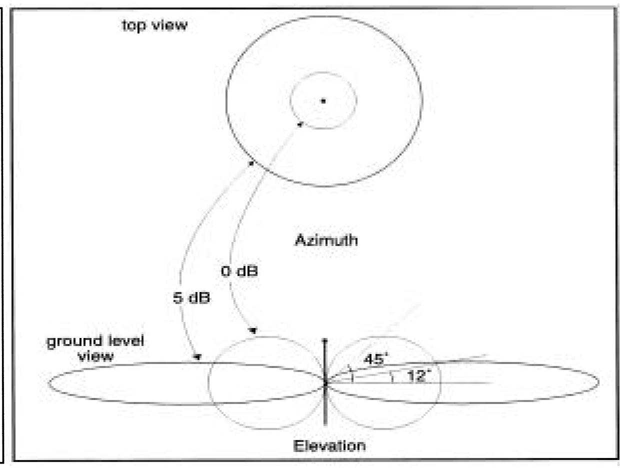
Zero Baseline Calibration Equipment: *Zero Baseline* (ZB) RF (collectively referred to hereinafter as "ZBRF") equipment is sometimes necessary to check GPS receivers to make sure that they are not biased during their performance. Electronic bias can yield differing solutions for *Earth-Centered, Earth-Fixed* (ECEF) coordinate positions and related vector measurement. While ZB testing may be performed during manufacture, it is a good idea to check receiver performance on a periodic basis similar to checking the calibration of a tribrach, level vial or bulls-eye bubble, for instance.

ZBRF equipment consists of a special “*splitter*” which allows two or more receivers the ability to connect to a single antenna while maintaining the required 50-Ohm impedance. The splitter allows a good signal to noise ratio and also helps to avoid injury to the receiver’s internal components. However, check the manufacturer's warranty restrictions prior to performing this test.

UHF Antennae: UHF antenna applications are another area of importance the District explored in detail. The type and various design complexities of antennae are correlated with a corresponding cost relationship. Antennae are usually tuned to a center frequency among a range of the spectra (e.g. centered upon a 10 or 20 MHz range for RTK UHF, as well as other applications).



DIRECTIONAL ANTENNA RADIATION PATTERN



OMNI-DIRECTIONAL RADIATION PATTERN

There are also different types of antennae. The majority of these antennae for RTK will either be called *Omni-directional* or *Directional*. As can be detected from the antenna radiation diagrams, the transmission patterns for these two antennae are synonymous with their names.

Antennae can be ordered with *Gain* incorporated within their design. Gain antennae are engineered to perform with an extended radiation pattern. It is common to see ratings of 3-dB or 6-dB gain, for instance. Try to remember that a good rule of thumb is that a nearly doubled “*Effective Radiated Power”* (ERP) is achieved for each 3-dB of gain. Care is needed in that users may easily “exceed” licensed ERP allowances.

In example of the preceding, using a 35W amplifier and a 6-dB gain antenna under a license issued at 35W ERP for mobile applications equates to an overall operational ERP of approximately 140W. It seems apparent that perhaps this configuration exceeds the licensed allowance. The result of breaching an ERP license is not limited to potential FCC violations and fines alone. In addition, this most likely causes system inter-modulation problems, as well as other related co-user problems. The actual impact depends upon the local environment and/or associated natural attenuation, etc.

Data Share Servers: If the user's choice is to offer Static related data online, it will become evident that there are many choices. Each choice requires specially related software and in some cases additional specialized hardware. One alternative is to set up a bulletin board service for telephone access using a *File Transfer Protocol* (FTP) server.

The District chose to use the Internet for data sharing. The seemingly obvious benefit using the Internet is that the ability to reach users is nearly unlimited allowing datashare to more potential beneficiaries. Specifically, communication gaps are thus bridged which therefore allow *Universal Reference Listings* (URLs) and associated data to reach beyond conventional notices found within professional publications and trade bulletins, etc. Users can also find the site by using standard Internet search engines.

The District's Internet site utilizes standard *Hyper Text Markup Language* (HTML) programming. The specific data-sharing portion of the District's site utilizes UNIX© *Practical Extraction Report Language* (PERL) programming that incorporates a framed style configuration for file separation and data-share offerings. http://www.lvvwd.com/data_share/gps.html.

An Internet site also allows the addition of provenance information for users who are concerned with liability and related accuracy statements. It is the author's professional opinion that as land surveyors we should be aware of where our data is coming from, and to what purpose the level of accuracy is intended to serve.

Without provenance information professionals can't otherwise assure that they are maintaining the competency required by various state and federal standards. The preceding fact may be somewhat alleviated upon recognition of statistical indicators. However, constraining to incorrect or low-accuracy values will result in spatial or geo-referencing related problems.

In example, statistics are not the only requirement for Nevada land surveyors. *Nevada Revised Statutes* (specifically NRS 327.060, 2) require provenance (source) information when *U.S. State Plane, transverse Mercator projection* coordinates are reported on a survey report or plat. Also, the addition of provenance related information within the Internet site lends credibility to the hard work and dedication exercised during the performance of erecting an MGBS.

An additional benefit using the Internet can consist of providing users an e-mail link that is useful for those that have random difficulty downloading data. In example, on rare occasion the District's network server fails. As a result, data remains dormant in the local land survey repository. Subsequently, these data can't make the transition to the Internet server. The e-mail link is therefore useful to allow the conveyance of important messages to the District's *Land Survey Section* (LSS). If the LSS has not internally noticed a lapse in Static data service (which would ultimately surface a day after upload to the server), user messages therefore trigger the LSS to contact the District's *Information Systems* (IS) department to bring the system back to a functional status.

Property Acquisition: *Property Acquisition* (PA) is an area that can create some difficult problems if not well researched in advance. PA can also require fees under some circumstances. Does the proposed location best serve the needs of the majority users and what is the site's suitability as related to the criterion listed under the "*Geological Substructure and Subsidence*" section within of this paper?

Will the provider of the MGBS lease, purchase or file for right-of-way? Who does the property belong to and what insurance issues must be met to ensure the safety, health and welfare of the public? What is the cost for the applicable insurance and what are the associated coverage listings and exceptions to policy?

Fortunately, the District owns all properties utilized to support the primary MGBS system. In the case of the digi-repeater sites, the District has acquired property rights under other community support group's leases. Perhaps as a *Professional Land Surveyor* (PLS or RLS, etc.) you may be called upon, or may desire to provide services to draft and seal a legal description for incorporation within an easement indenture to secure rights to construct and maintain the MGBS and/or digi-repeater.

Other considerations regarding PA surround issues relating to security and securability. GPS and associated equipment is very expensive. Weather and relative accessibility is another factor. This paper has already covered power issues and it will further cover wireless communications. An additional question is: "Are there any local obstructions to satellite reception? Perhaps the most revealing way to answer this question is to set up some GPS equipment and let the receiver collect *Full-Wave Static* (FWS) data for approximately 72 hours, more or less. It would be a good idea to review the satellite tracking summaries for any unusually irregular cycle slips denoted within the tracking indicator graphs.

V. Positional Certainty, Accuracy Considerations and Liability

Ultimately during the process of establishing an MGBS a requirement to determine the precise location of the L1/L2 antenna becomes evident. As eluded earlier within this paper, care must be exercised when sharing information with PLS' and others who rely on these data. Positional certainty, relative accuracy, and liability concerns of today and tomorrow are examples of considerations that must be made in order to impart and ensure a high level of confidence in the system.

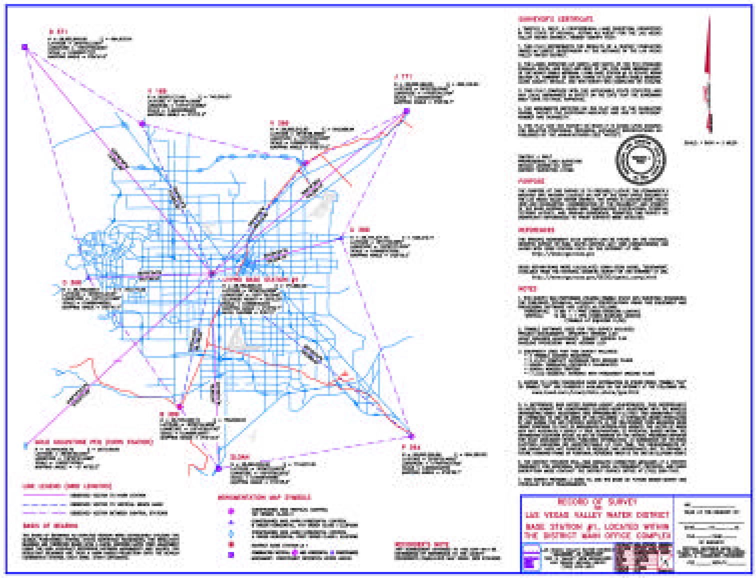
This paper has already shared information concerning the fact that our primary commitment for the service of this MGBS is to our internal operations, namely the District, SNWA and SNWS departments and divisions. However, there is also a relative but seemingly higher burden placed upon the provider to assure a competent level of commitment to the public upon sharing this kind of information.

The thought process regarding the issue is somewhat analogous with sharing a glass of water. Does the glass contain contaminants? Will the contaminants make the "beneficiary" sick or worse infect them with an infectious or vicious disease? It was this kind of pressure and responsibility that provided a portion of the impetus to test this system and subsequently write this paper.

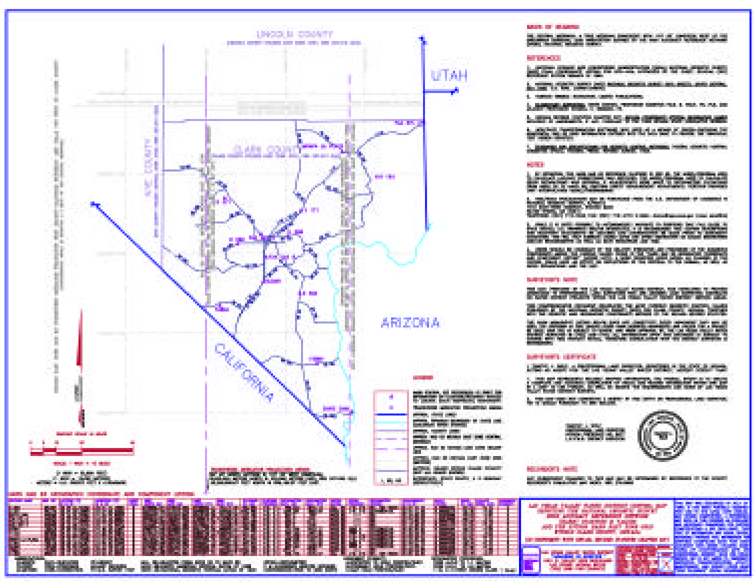
Base Antenna Adjustment Process: The position for the District's MGBS antenna was established utilizing Static GPS surveying techniques. The controlling network fully enveloped the MGBS position. The horizontal control used to constrain the final adjustment was comprised of five (5) Precision *B Order* (1:1,000,000) monuments and one (1) Precision *A Order* (1:10,000,000) CORS Station. All control listed conformed as precision *4th Order, Class I,* ellipsoidal components per NGS HARN *Federal Geodetic Control Sub-committee* (FGCS) documentation.

The resultant field vectors were measured and subsequently adjusted utilizing a Least Squares (LS) solution constraining these six (6) control monuments. The *Modeled Orthometric Elevation* (MOE) was established using seven (7) *1st Order, Class II,* and one (1) *1st Order, Class I, Federal Geodetic Control Committee,* (FGCC – applicable to era 1994) NGS, *North American Vertical Datum of 1988* (NAVD88) monuments. Preferably all control is NGS *Stability A* (Expected to hold elevation/position) and is therefore located within in areas less susceptible to subsidence or preferably located within a rock outcropping.

The vertical component was also adjusted by an additionally separate LS solution utilizing NGS' GEOID96 as a geoid model. All field observations consisted of multiple sessions and resultant vector measurements to ensure redundancy. The District's minimum occupation time for any single monument employed within this network is currently thirty (30) minutes per session. Each session is performed under favorable pre-planned satellite geometry. The most favorable satellite geometry *window* (periods when the satellites were at optimum strength) was calculated using Trimble's© *Quick-Plan*© software. The program also allows the addition of obstruction survey information to denote potential obstacles to GPS signal reception.



CURRENT LVVWD HARN-BASED MGBS ADJUSTMENT MAP
FILE 96, PAGE 77 OF SURVEY MAPS, CLARK COUNTY RECORDER'S OFFICE, NEVADA



LVVWD CONSULTANT REQUIRED-USE, 1994 HARN MONUMENTATION
FILE 2, PAGE 32 OF MISCELLANEOUS MAPS, CLARK COUNTY RECORDER'S OFFICE, NEVADA

PROFESSIONAL ENGINEERS AND SURVEYORS

NAC 625.666 Positional certainty: Horizontal and vertical components of certain land surveys. (NRS 625.140, 625.250)

1. The requirements for positional certainty for the horizontal component of land boundary, topographic, control and geodetic surveys are as follows:

Type of Survey	Positional Certainty	
	Meters	U.S. Survey Feet
Land Boundary Surveys		
High Urban	±0.02 m	±0.05 ft
Low Urban	±0.04 m	±0.15 ft
High Rural	±0.1 m	±0.3 ft
Low Rural	±0.15 m	±0.5 ft
Control and Geodetic Surveys		
Precise Measurement Studies	±0.001 m to ±0.01 m	±0.002 ft to ±0.03 ft
State Network	±0.02 m	±0.05 ft
County Network	±0.04 m	±0.15 ft
Local Network	±0.06 m	±0.2 ft
Photogrammetric Control	±0.06 m to ±1 m	±0.2 ft to ±3 ft
Topographic Surveys		
Engineering Design Surveys	±0.01 m to ±0.1 m	±0.03 ft to ±0.3 ft
Planning Study Surveys	±0.02 m to ±0.05 m	±0.05 ft to ±0.15 ft
Utilities Mapping	±0.15 m	±0.5 ft
Feature Mapping	±0.3 m	±1 ft
Resource Mapping	±0.5 m to ±100 m	±1.5 ft to ±330 ft

2. The requirements for positional certainty for the vertical component of land boundary, control, geodetic and topographic surveys are as follows:

Type of Survey	Positional Certainty	
	Meters	U.S. Survey Feet
Land Boundary Surveys	±0.05 m	±0.15 ft
Control and Geodetic Surveys Other Than Photogrammetric Control Surveys	±0.005 m to ±0.03 m	±0.02 ft to ±0.1 ft
Photogrammetric Control Surveys	±0.03 m to ±0.5 m	±0.1 ft to ±1.5 ft
Topographic Surveys	National Map Accuracy Standards	

3. For the purposes of this section, the National Map Accuracy Standards, as they existed on November 14, 1997, are hereby adopted by reference. A copy of the National Map Accuracy Standards may be obtained from the United States Geological Survey, Department of the Interior, 12201 Sunrise Valley Drive, Reston, VA 20192, at no cost.

(Added to NAC by Bd. of Professional Eng'rs & Land Surv., eff. 11-14-97)

POSITIONAL CERTAINTY REQUIREMENTS FOR NEVADA PROFESSIONAL LAND SURVEYORS

Professional Liability: Not unlike other state's standards, professional liability regarding positional certainty for data conveyed on a survey plat rests with the Nevada PLS. As is evidenced from the above performance categories at the 95% (2-sigma) confidence interval vary depending upon the type of survey engaged. This process requires statistical analysis of field data and an incorporation of an appropriate statement within the survey plat. This statement denotes the level of the survey as noted within the above reference. Specific requirements for land and construction surveys are found within Chapter 625 of the *Nevada Administrative Code*, NAC 625.666 and 625.675, respectively.

Subsidence and Movement: This paper has already discussed the importance of the geological substructure and subsidence related issues. However, the following is the specific caveat emptor the District incorporated within our Internet site. Keep in mind the fact that currently there are no fees charged for data download.

The base station antenna is mounted upon a fixed mounting platform located approximately 5 meters above the ground surface. The mounting system is directly bolted to the building structure affixing the antenna to the building parapet wall. The

Las Vegas Valley has a history of being susceptible to subsidence at times, which may have an effect upon the base station antenna providing the control values.

The nature and magnitude of the subsidence as specifically related to ground water demands is currently not precisely known or predictable. In an effort to correct and maintain the base station position, an adjustment equal to or better than the original field occupations and network will be performed on a 6 month basis. Thus far during the past three (3) surveys, insignificant differences were noted with respect to the independent antenna position adjustments.

The District's main office complex is located near the center of the valley. For more information on subsidence, see the previously covered section entitled "*Geological Substructure and Subsidence*". The District's disposition regarding the above caveat is that, as stated previously within this paper, there has been an inability to detect any movement and the InSAR supports our statistical analysis from a recent historical prospective.

However, based upon the valley's historical maps as provided by the *Nevada Bureau of Mines and Geology* (NBMG), the District is not comfortable removing the caveat statement from within the Internet site. Additionally it is fair to state that at this point no one can predict episodic events or the potential of future subsidence. As such, the caveat will remain.

During periods of low demand the District implements an *Artificial Recharge* (AR) program. Within this program treated water is injected into the Las Vegas Artesian basin. As a result, the District is confident that the detection of rising ground water levels is realistic. A handful of wells that were historically known to be "artesian" have once again pressurized. However, it is hard to accurately determine the total impact to the valley's hydrologic system as a function of the AR program. Variations in precipitation are monitored and other cycles are studied that appear associated with these processes. The valley's water supply is currently supported on an approximate 15/85 percent basis; groundwater to Colorado River water, respectively.

Data Liability: Not unlike other organizations, the District has compiled a statement of understanding that must be accepted prior to proceeding to the data-share section of the site. This statement is also included within this report. Those who are contemplating the establishment of an MGBS can review the message's importance and its applicability for inclusion within their data-share Internet site.

A statement of understanding between the Las Vegas Valley Water District (District) and any and all subsequent users of information obtained here from. These files and supporting information is furnished by the District and is accepted/used by the recipient with the understanding that the District makes no warranties, express or implied, concerning the accuracy, completeness, reliability, or suitability of the files, *or its constituent parts, or any supporting data. It is further understood that all users are acting at their own risk.*

The District shall be under no liability whatsoever resulting from any use or misuse of this information. This information should not be relied upon as the sole basis for solving a problem whose incorrect solution could result in injury to person or property. These files are the property of the Las Vegas Valley Water District. Therefore, the recipient further agrees not to assert proprietary rights therein and not to represent this information to anyone as being other than belonging to the Las Vegas Valley Water District.

The last sentence within the statement of understanding, above, is intended to provide notice regarding subsequent attempts to sell these data by users who download the files.

VI. Noteworthy Problems and Potential Solutions

Various applications of available equipment presented problems from time-to-time. These problems required unique solutions. The following covers some of the problems faced and subsequent specific solutions either envisioned and/or implemented. Some of these solutions and ideas are in part speculative. However, the future will undoubtedly determine the reality and feasibility of the stated solutions as they relate to the unknown.

A. Simultaneous RTCM-104 and CMR real-time Data Transmissions

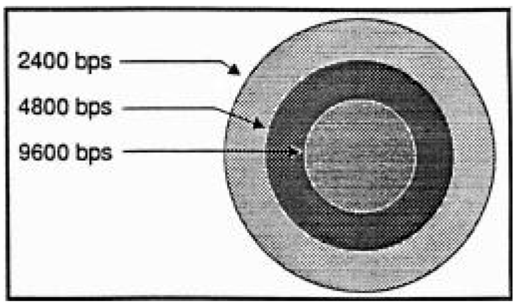
In order to support our non-engineering/surveying related uses of GPS discussed in the opening paragraphs, the District looked at the possibility of transmitting both RTCM-104 and the RTK *Compact Measurement Record* (CMRon the same frequency. (To save repetition, the simultaneous broadcast of RTCM-SC104 code phase data along with CMR carrier phase data are collectively herinafter referred to as "CRT") CRT presents no problems itself because of Trimble's foresight regarding this issue. CRT functionality has been within the URS software for years. Trimble's© CRT data format consists of a combined, but abbreviated version of what a complete CRT merge would have been.
However, the Trimble CRT message contains approximately 4,400 Bits. Since this message is rather large it may require a minimum over-the-air baud rate of 4800 *bits-per-second* (bps) to provide proper functionality. Also, if users want to repeat the message they have to change to an over-th-air 9600 bps rate. However, users are limited to one digi-repeater as real-time messages are transferred within an interval of one second. Since most radios are capable of transmitting and receiving at 9600 bps, the *Southern Nevada GPS Sub-committee* (SNGS) is considering standardizing this data transfer rate for our valley-wide UHF RTK-only systems.

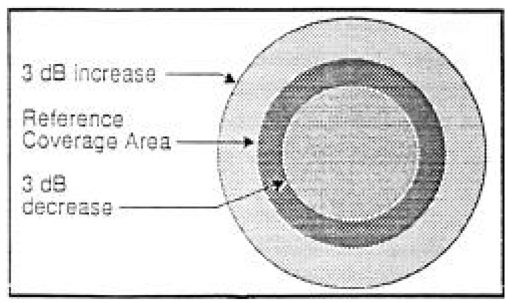
Further CRT problems surface at a 9600 bps baud rate when a user desires to repeat from more than one digi-repeater. There is insufficient time remaining before the MGBS starts transmitting the next combined message. The potential pitfall is that channel overload or co-channel interface is created on the same frequency used for the data transmission at the

MGBS. Under this scenario, radios can become confused and/or desensitized and cease their ability to receive complete packet data and subsequently perform a checksum process. Ultimately the modems won't operate efficiently, if at all, under these circumstances.

A seemingly easy solution to enable CRT repeating might be to raise the over-the-air baud rate to 19,200 bps, for instance. However, this presents a new set of problems. Some of these problems surround available equipment and others are related to coverage loss associated with a higher data transmission rate. An increase of baud rate from 4,800 to 9,600 bps, for instance, constitutes an approximate loss of 41% coverage if all else remainsfixed, using an R^2 model. (R^3 and R^4 models also exist and are often employed in software designed to help radio engineers to predict coverage patterns).

As the Baud rate increases, the energy per bit decreases, thus the reduced coverage is due to this decreased energy per bit, along with other propagation related problems. Of minor consideration is that the modem processing time, called "*throughput,*" is generally increased by increases in baud rates. This is in part because, commensurate with these increases, the modulation systems become more complex. This also compounds the data length problem somewhat. The following graphics provide an overview of the general idea.





IMPACT OF SIGNAL LEVEL CHANGES **SYSTEM COVERAGE AREA VS. DATA SPEED**

One solution to the extended data packet problem might be to devise a program that sends each message separately on an alternating basis. It may be possible to transmit CMR for one second and then RTCM-104 the next, and so on. There are other problems with this process that would need to be worked out, such as the fact that there is additional information contained within every 10^{th} & 5^{th} CMR messages. The importance of that information might be crucial to the overall operation of RTK. Minor latency doesn't appear to be an issue during the author's experience concerning reception and use of the CMR message.

The seemingly obvious, but expensive solution to this data packet problem is to erect two antennae, as well as two amplifiers, and apply for a second frequency. Based upon these CRT problems transmitting combined messages; the District found it much more cost effective to use RTCM-104 services broadcast from geosynchronous satellites (GEOS) for RTCM-104 differential GPS reception. More information on satellite based delivery platforms will be provided within the following section entitled *Earth Orbiting Satellite Technology* section, located within this paper.

It is appropriate to note herein that the proposed introduction, expected around 2005, of the new *L5 Civil Signal* (1176.45 MHz) could also possibly have an impact on RTK packet data message lengths. It is envisioned that the correction messages for RTK might need to be lengthened. Under this scenario the addition of the L5 might likely compound the CRT data packet length problem as well.

B. Pushing the "Limits" with RTK

The District built our MGBS system to incorporate digi-repeaters to provide a large coverage area for RTK. In fact, the District's UHF coverage extends valley-wide and beyond. The Las Vegas valley area consists of approximately 35 square miles. The impetus for designing this extended coverage rests within the fact that our internal operations require varying tolerances.

In example, sometimes the *Land Survey Section* (LSS) is called upon to measure elevations at proposed reservoir sites. These tolerances are plus or minus about one-half foot vertically. This process saves time during the District's facility *Property Acquisition* (PA) phase. This is because the system can be used to identify a location's suitability to fit within our hydraulic zone coverage. RTK operation under this procedure thus saves the District time. The District might otherwise work to acquire an unsuitable parcel from the *Bureau of Land Management* (BLM) or a private party or otherwise rely on less efficient differential level solutions.

The next logical question asked was *"How far can users extend RTK technology from the MGBS?" and "What will the expected accuracies produce under variable conditions?"* As with any equipment land surveyors can't fully rely upon the technical accuracy specifications listed for the equipment as published by manufacturers. Protection from litigation while also assuring professional integrity requires statistical approximations and a sound analysis of residuals.

Another question pondered was "*When can users meet specific tolerances?*" and "*During accelerated project timelines, how quickly and when can users meet varying survey requests?*" Other questions were "*Can users begin to predict potential RTK solutions or accuracies prior to or during a survey*" or *"Are there any correlations to support or reject the mere thought of the preceding question?"*

It should be somewhat common knowledge that the majority of manufacturer's technical accuracy specifications are generally listed at the 68% (1-sigma) confidence interval. However, federal and Nevada standards require values to be reported at the 95% (2-sigma) confidence interval. Therefore a calculation would certainly be useful to evaluate the 2-sigma equipment "limits." A diagram depicting the approximate relationships discussed previously is shown below.

Technique	1 Sigma	2 Sigma
RTK (Horiz)	+/-(1cm + (2ppm x BL))	+/-(2cm + (2ppm x BL))
RTK (Vert)	+/-(2cm + (2ppm x BL))	+/-(3cm + (2ppm x BL))
Static (Horiz)	+/-(5mm + (2ppm x BL))	+/-(7mm + (2ppm x BL))
Static (Vert)	+/-(8mm + (2ppm x BL))	+/-(1cm + (2ppm x BL))

APPROXIMATE 1 AND 2 SIGMA GPS EQUIPMENT ACCURACY SPECIFICATION EVALUATION

A caveat to the preceding values is that the majority of manufacturer's technical accuracy specifications also incorporate associated minimum conditions that must be met in order to support the ratings at 1-sigma. Some of these include minimum satellite coverage, Dilution of Precision (DOP), as well as base-rover Range limits and *Root Mean Square* (RMS) values noted during use, etc.

However, logic would infer that manufacturer "limits" must be lenient due to concerns regarding potential misuse and subsequent frivolous litigation. The author has exceeded these specifications on numerous occasions as compared against direct HARN ties. The author will provide some linear statistics within his 1999 Trimble© User's Conference presentation that will show good, as well as bad population statistics. For HARN network accuracy specifications, refer to the "*High Accuracy Reference Network*" section of this paper.

Conventional traverses and differential level loops are closed and a precision is associated which is a representation of the confidence and the overall fit. Statistical analysis of GPS derived data is really not much different. The major difference from the days of the Bowditch and Transit rules, for instance, is that the *Least Squares* (LS) method of adjustment has become the standard due to the advent of the computer. GPS users should be familiar with the fact that LS adjustments are used within Static processors. However, some of the LS methods can be applied to post-RTK solutions as well.

Experiences has revealed that when users exceed the manufacturer's established base-rover *Range* (vector distance from the base to the rover)"limits" using RTK technology attention must be paid to many factors.

Examples of these requirements are: pre-mission planning, satellite orbital sky plots and related "*Dilution of Precision*" (DOP) diagrams, day vs. night surveying, higher mask or cutoff angle, repeated initializations, varying satellite availability, root mean square values and solar activity (formerly called *Coronal Mass Ejections* see http://sohowww.nascom.nasa.gov)

Pushing the "established limits" of *On-The-Fly* (OTF) and RTK technology can be very dangerous for the user who pays no regard to technology restrictions and other conditions yet expects Static level or manufacturer accuracy specification classed solutions. If the latter is the case the user will be “lucky” to meet the referenced specifications roughly 68 percent of the time. The resultant question the professional must in this case is “when and what is happening during the remaining 32 percent of the time?”

C. RTK UHF Licensing Issues, Alternatives and Relationships

Licensing in general is heavily regulated. An entire paper could be written about specifics relating to licensing beyond the FCC regulations. However, it would herein suffice to reveal the fact that the license process is very time consuming. Fortunately, there are alternatives. This section intends to highlight some of these areas that are germane to RTK solutions.

UHF Frequencies In General: Generally all private RTK UHF frequencies issued recently must share their place within the spectra with voice users. As stated under the *“Hand Held Scanner”* section of this paper, users must yield to voice transmission. As one could imagine, this can degrade the efficiency of the survey project thereby having an adverse effect on the budget. The itinerant frequencies that are issued when users are forwarded a *Conditional Special Temporary Authorization to Operate a Part 90 Radio Station* (CTAOPRS - FCC Form 572C) for private frequencies are another source of problems. This is because they are also voice and data shared frequencies.

CTAOPRS frequency solutions can be extreme burdens to communities in areas where a high volume of GPS survey crews operate. GPS equipment sales are booming, despite the temporary license orientation and the limit of merely four (4) itinerants. Also intinerants are currently the same four (4) frequencies for all new temporary users. In areas such as Las Vegas, there are few too many to effectively operate. Therefore a definite priority to MGBSs is to find alternatives to these problems. This is currently one of the most important secondary reasons to justify MGBSs.

Spread Spectrum Technology: *Spread Spectrum* (SS) technology is one alternative to UHF. It does not require user-direct licensing. The Federal Government has reserved a specific portion of the electromagnetic spectra for SS technology. Manufacturers are required to negotiate with the FCC to license and ensure compliance with applicable equipment restrictions. According to the latest information the author could find on this subject; users are currently restricted to a limit of 1-watt transmission capabilities.

This restriction limits the effective coverage area. Directional antennae can increase the coverage area. A downfall to SS is that in most cases using directional antennae requires realignment from time-to-time. Realignment requirements depend upon the proximity (*range*) from the rover to the MGBS or digi-repeater. See the “UHF Antennae” section for pattern coverage.

Spread Spectrum technology takes advantage of the available spectrum by constantly changing frequencies. Bits of the messages are *"spread"* over different frequencies *bit-by-bit* (or *packet-by-packet*) within the allocated spectra using the various available frequencies.

The system quickly scans for available frequencies, secures one and then sends header information along with the data packet from the *"master"* radio modem (at the base station or repeater) to the *"slave"* radio modem (at the rover). The transfer of header information gives the message from master to the slave. This relationship transfers the appropriate new frequency for the next message, and so on and so-forth. This process as described herein is informally called *frequency hopping.*

As stated earlier, most manufacturers of SS are *Type-Listed* (TL) for Directional antennae. There is at least one manufacturer known to the District that is TL for SS use using Omni-directional antennae. SS could solve multiple digi-repeater UHF desensitization problems for individual digi-repeater to rover setups discussed previously within this paper.

Solving the previous problem could be achieved whereby SS users receive RTK UHF from the MGBS and then transmit license-free using a 1-watt SS radio modem. It is recommended that those who are interested in SS should conduct further research on SS technology system solutions. Additional guidance should be sought from manufacturers or the local radio supply vendor regarding specific operation restrictions.

Cellular Digital Packet Data: *Cellular Digital Packet Data* (CDPD) was another area the District explored. This technology takes advantage of the already existing (and growing) cellular telephone repeater networks. Direct user licensing is avoided. However, coverage degrades near obstructions and the technological advancements are currently somewhat limited.

A service provider charges a fee on a per-kilobyte basis. RTK CDPD in the Las Vegas area would approach a fee upwards of about $30.00 per month. However, this is a function of the use. Keep in mind that RTK GPS data packets consist of a short message. Additionally, these messages are not continuous.

CDPD also uses an advanced type of Spread Spectrum technology but the antennae cell sites constitute a more densified coverage at no direct expense to users. Problems implementing this technology were due to the fact that *multiple-user* (ability for many to receive the same data) technology has not yet been fully developed. Current cellular telephone systems are primarily designed for person-to-person communication. Development of this potentially beneficial system is probably hinged within a supply and demand scenario. Current demand for CDPD RTK solutions is very low.

Sub-Carrier Technology: *Sub-carrier Technology* (SCT) is another area of potential benefit to GPS Real-Time users. Similar to other standard radio transmissions the SCT would be inaudible to humans. Radios would somehow segregate information intended for broadcast with that intended for RTK. Humans speak rather slowly as compared to the *speed-of-light* travel of radio waves. As a result, SCT occupies the spaces between the radio stations "voice" transmissions. To my knowledge this system is not currently in operation for GPS.

SCT is somewhat analogous to the benefits of CDPD, but the transmission would come from local radio stations. This may offer a better solution because radio stations providers are afforded higher ERP licensing. Interested parties should perform further research to learn the direct benefits. The realization of this technology is probably also hinged within a supply and demand scenario. Current demand for SCT RTK solutions seems very low.

Earth Orbiting Satellite Technology: This paper has already conveyed brief coverage of *Earth Orbiting Satellit Technology* (EOST) technological information. See the section regarding "Simultaneous RTCM-104 and CMR Real-Time Data Transmissions." It would suffice to say herein that EOSTs consist of a group of geo-synchronous satellites. These EOSTs transmit C/A messages with specific format information as to only allow those who continue subscribing the ability to use the data. In example, one system utilizes the last four numbers of the GPS receiver's EOST antenna serial number. Parties interested in EOST advantages should seek further guidance.

However, one example of a corporation that provides EOST correction message technology generates the data outside of the boundaries of the state of Nevada. However, this EOST overage is almost unlimited, the fee is reasonable, and the associated accuracy (accuracy < 3 meters) meets the needs of our GIS Analysts with most of their projects. When the latter is not the case, they commission the District's *Land Survey Section* (LSS) to secure spatial information for project incorporation and geo-referencing.

Microwave Technology: The District owns and operates two RTK UHF digi-repeaters. One is located on Apex Mountain and the other on Potosi Mountain. Their elevations are about 4,800 and 8,600 feet respectively. The Las Vegas valley floor rests at an average elevation of about 2,600 feet. Currently the District is repeating using UHF simplex technology. The District is within about 2 weeks of finalizing a microwave link that will transfer data from the valley floor to the mountains using the more secure and better-equipped microwave technology.

A local telephone company can provide the service if available. Under this arrangement, the service provider therefore solves any associated licensing problems. Implementing a microwave system requires long-range modems and other technology beyond that which the provider will offer on a standard basis. A major benefit herein is that users are not burdened by licensing requirements.

Fees for microwave systems are assessed locally at upwards of about $60.00 per-month per-"line" (circuit of allocated air space). Of major benefit is the fact that these circuits are dedicated. However, the fees can vary and are sometimes governed by the amount of central offices the data passes through during transfer.

After the District’s RTK data is received at the mountain sites the data packets will be delivered via “*Dry Pair*” (*Telco Data Circuit* - TDC) hardwire lines to modems. After TDC reception, the data will be demodulated using the long-range modem. Then the information will be passed to UHF transmitters for over-the-air transmission to RTK rovers. It is envisioned that the District’s ability to operate within our valley will be unparalleled elsewhere.

Wide Area Differential: *Wide-Area Differential GPS* (WADGPS) solutions might become more advantageous and available for C/A applications. However, the District has not found the need to perform research in these areas. Mention is made to direct interested parties to perform their own research on this subject.

Public Safety Frequencies: If groups and/or individual users can partner with other agencies, specifically public administrations, they have a better opportunity of obtaining a *Public Safety Frequency* (PSF). *Public Service Administrations* (PSAs) must work with the *Associated Public Safety Communications Officials* (APCO) located within their state. This is a group of police and other emergency oriented officials.

PSFs are generally handled by APCO acting as liaison between the requesting agency and the FCC. Conversely, under normal circumstances the public sector must hire a consultant and thenceforth function within a limited capacity with the FCC. Probably the best news for PSFs is that the frequencies are dedicated to a single organization. They are very nearly local "exclusive-use" frequencies. (If there is such a thing as “exclusive-use.”) PSFs alleviate many problems associated with the described voice-data licensed frequencies.

In order to prove the need for a public safety frequency; it is beneficial to highlight and incorporate any potential benefits to the public and their safety. The District met these requirements because potable water and the construction of related infrastructure is a public concern. Another reason that supported our PSF application is that since Las Vegas is located in the Mojave Desert, the availability and service of water is crucial to the health, safety and welfare of the public.

In addition there are many acts of Nevada Legislature, which require the District and its related branches to adhere to applicable public safety law. A good example is found within the *Nevada Revised Statutes* (NRS 455.082). This regulation requires utility companies operating underground infrastructure to locate and mark their buried infrastructure to within 30 inches horizontally before any construction activity can commence. This is otherwise known as Nevada’s “*Call Before You Dig.*”

In example, if utility companies do not properly locate their facilities and they are disturbed by the developer, or contractor, etc., the locating utility must pay to have that particular infrastructure repaired.

D. Shared Use Agreements for UHF Frequencies
It is fairly clear that if a party desires to establish an MGBS for RTK; of primary importance is the ability for these communities is to make the data available to as many users as possible without saturating the airwaves. In some cases the RTK UHF radio modem restricts reception by make, keying, etc. Therefore, standardization is key to making the system available for all.

What can be done when users get into a “shadowed” area where there exists a pocket that the MGBS radio's transmission cannot reach? The obvious solution is to set up a digi-repeater in an area where reception is adequate. However, digi-repeating with UHF is transmitting. Transmitting requires a license or a *Shared Use Agreement* (SUA) with the licensee.

Another option to this scenario, as pointed out earlier under the “*Spread Spectrum Technology*” section of this paper, would be to receive the UHF outside the shadowed area and then direct that received information to a S*pread Spectrum* (SS) master. Further, transmit the data on the SS system and connect another SS slave to the RTK rover. Recall that the SS system does not require a direct user license. Also recall that SS can be individual repeater-rover specific. This system won’t effect the performance of your UHF neighbor’s UHF RTK operation. This is a benefit. However, also recall that certain restrictions govern use of SS technology.

In the absence of SS radios and/or an applicable budget, licensees who desire to establish RTK UHF *Shared Use Agreements* (SUAs) must consider everyone using the system. The FCC authorizes SUAs under certain conditions. However, the licensee might be ultimately responsible for infractions of applicable law. To some degree SUA users carry a proportionate responsibility. In any event, it is advisable to create and execute a written agreement that explains the responsibilities of each party. For further information refer to CFR Title 47, Part 90, section 90.179 entitled "Shared use of Radio Stations." http://www.fcc.gov/wtb/rules.html

A handful of the specific areas that the District is incorporating in our agreement are herein listed. During SUA scenarios providers may want to limit the UHF digi-repeater ERP to about 1-watt or less but this is somewhat dependent upon the local environment as stated previously.

Limiting the digi-repeater output to 1-watt thus becomes similar to the advantages of SS technology restrictions but adds potential multiple digi-repeater SUA difficulties. However, as stated previously attenuators work very well in the case of the UHF digi-repeat scenario. The reason for requiring limited wattage is due to desensitization issues discussed previously. The result of not placing limits on SUA ERPs can effect others working in the immediate vicinity of the newly erected temporary digi-repeater. This can defeat the purpose of an MGBS.

Perhaps the SUA may require a fee for this service to maintain the equipment used to keep the system functional. Also, what will be the provider's recourse if they repeatedly find that a user is violating the terms of the agreement? A *Breach of Agreement* clause, or clauses, and fines or expulsion from the benefiting terms of the SUA for persistent violators must be considered.

When the provider creates a system primarily for internal use, it appears obvious that they cannot allow sharing problems. SUA providers share because of a concern for public benefit and a secondary benefit by a reduction of cost for consultant work. This is realized in that the District will soon require that its consultants use the system to reduce expenditures and increase efficiency.

Making SUA rules and regulations known to the professional in advance will help alleviate potential problems over the course of operations. Justifying the extra cost for additional SS radios is somewhat easy upon review the potential problems evidenced above.

Organizations that are going to offer this RTK UHF information as a public service must consider standardizing the asynchronous *Protocol* of the over-the-air data packets within the SUA. Such protocol can consist of *Parity* (Odd – Even – None), *Baud Rate* (2400, 4800, 9600, 19200, etc.), *Databits* (6, 7, 8, etc.) and *Stop/Start Bits* (1, 2, etc.). Some of the variables mentioned would be a function of the radio modem chosen to employ. Compatibility and the ability to share become specifically important when communities start adding more MGBS (especially RTK-only).

VII. Closing Statements

The author realizes that, due to the preceding dynamics, generally no single individual will posses the ability to fully determine the specific needs for an MGBS. A structurally sound MGBS is the result of effective teamwork consisting of many professionals. As stated earlier in this paper, and as evidenced herein, the variables and complexities can be vast. There are so many issues one must take into consideration. It should be abundantly clear that each decision carries an associated financial impact.

Every project is limited by a combination of budgets and the abilities or inability to dream and thence create or solve a particular problem. The author has done some dreaming and without that kind of ingenuity, nothing would have ever been created. The District’s system is functional for many purposes. Review of our Internet “hit list” will evidence the fact that the system is truly serving the needs of the public and our consultants. This indirectly achieves a higher overall efficiency which saves rate payer dollars as well as serves to unify the District’s spatial data quality and related products.

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