Reference Study: ngVLA Buildings and Infrastructure

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1.0	2018-09-28	Langley	Initial draft.
2.0	2018-10-10	Langley	RIDs from Internal Reference Design incorporated.
3.0	2019-07-25	Langley	Revised Section 8.1 and Table 1, added RD05
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1 Introduction

The National Radio Astronomy Observatory (NRAO) is proposing the design and construction of a new astronomical observatory that will operate at centimeter wavelengths. The majority of the Next Generation Very Large Array (ngVLA) antennas will be located in the vicinity of the current Jansky Very Large Array (JVLA), with additional elements located in New Mexico, adjoining states, northern Mexico, and targeted locations throughout the hemisphere.

The ngVLA will ultimately replace the JVLA. A portion of the proposal effort includes an assessment of building and infrastructure needs. Building location recommendations and cost estimates for buildings and infrastructure to support the ngVLA mission is also required. This document will discuss each and, based on the findings, provide a costed reference recommendation for ngVLA buildings and infrastructure. With consideration to

1. the project mission,
2. existing NRAO facilities and utilities that may be leveraged,
3. the ngVLA operations concept [AD01],
4. environmental concerns, and
5. the overall construction cost,

this report recommends that the number of staff permanently stationed close to the antennas be minimized.

To accomplish this, we propose considerable changes from JVLA operations in the location from which support staff operate. Along with the infrastructure and antenna pads needed to support the central antenna group, the central ngVLA site should be outfitted with a new, partially submerged processor building along with another structure or structures to serve as heavy equipment support facilities. Building a new campus located 24 miles east of the array in Magdalena, NM, is recommended to facilitate immediate antenna repair. Employees at this location would be responsible for replacing failing line replaceable units (LRUs), regular maintenance activities and the storage of spare LRUs, and regular preventive array maintenance. Array support staff such as Environment, Safety, and Security (ES&S) would also be located in Magdalena.

Engineers and technicians who perform repairs requiring a higher level of technical expertise are recommended for a new Socorro, NM electronics facility. Although a considerable number of observatory support staff would necessarily remain located at the Domenici Science Operations Center (DSOC) in Socorro, NM, to improve the recruitment and retention of staff and ease travel, scientific, array computing, and observatory support staff could be located in a major metropolitan center.

During construction, several assembly/integration centers are required. This report identifies each and which of these can be repurposed for ngVLA operations support.

2 Project Background

The ngVLA is a project of the NRAO to design and build an astronomical observatory that will operate at centimeter wavelengths (25 to 0.26 centimeters, corresponding to a frequency range extending from 1.2 GHz to 116 GHz). The observatory will be a synthesis radio telescope constituted of approximately 263 reflector antennas, most 18 meters in diameter, operating in a phased or interferometric mode.

The signal processing center and 187 antennas will be located in the vicinity of the current JVLA site, on the Plains of San Agustin, New Mexico. The array will include 46 mid-baseline stations in other locations throughout the state of New Mexico, west Texas, eastern Arizona, and northern Mexico. Thirty long-baseline antennas will be distributed between ten sites, many of which are the present locations used by the Very Large Baseline Array (VLBA).

Operations will be conducted from both the ngVLA Processor Building and the Science Operations Center (DSOC) in Socorro, NM. Scientific and Computing staff may be located in a yet undetermined metropolitan area.

3 Related Documents

3.1 Applicable Documents

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA Operations Concept	020.10.05.00.00-0002-PLA
AD02	Environmental Specifications	020.10.15.10.00-0001-SPE
AD03	Assessment for Very Large Array Facility – Including Site Infrastructure, Control Building, & Site Buildings	020.60.00.00.01-0002-REP

3.2 Reference Documents

Ref. No.	Document Title	Rev/Doc. No.
RD01	2018 Building Construction Costs with RSMeans Data	ISBN 1946872016
RD02	ngVLA Radio Frequency Interference Forecast	ngVLA Memo #48
RD03	Long Haul Fiber Workgroup Preliminary Report	020.60.00.00.00-0002-REP
RD04	Transition Concept	020.10.05.00.00-0003-PLA
RD05	ngVLA Core and Plains Power Infrastructure	020.60.00.00.01-0003-DWG-A-NGVLA_ONE_LINE

4 Scope

This document includes requirements and costing information for the buildings and support facilities that directly support the ngVLA. The infrastructure located at the ngVLA core, plains, and remote areas will also be addressed.

Several items are not included in the scope of this reference study. Because other efforts to plan for a Visitor Center are taking place through the Education and Public Outreach department, an ngVLA Visitor Center is not included in this study. Costing for the various shop equipment or support vehicles, fiber system components (other than the buried fiber itself), cost of land, and easements are not within scope, nor are long fiber runs not associated with the main site, such as the run between Socorro and the ngVLA site, and cross-country rented fiber. These are addressed in [RD03], ngVLA Long Haul Fiber Workgroup Preliminary Report.

The eventual decommissioning of the JVLA antennas, buildings, and infrastructure is also considered outside the scope of this document, though budgetary estimates are provided in the appendix.

5 Operations Infrastructure Concept

Key aspects of the operations infrastructure concept as described in [AD01], ngVLA Operations Concept, are repeated in this section. The material presented in the most recent version of [AD01] supersedes any material included here.

The operations concept requires specific support infrastructure. Workspace sizing estimates have been developed, though these are preliminary and will be revised and expanded as part of the overall operations plan. To streamline operations and to minimize RFI, it is desirable to limit the number of staff and operating equipment located on-site in lieu of working out of a nearby Maintenance Center, perhaps located in Magdalena, NM. A majority, if not all, of line replaceable units (LRUs) and equipment is expected to be located at the Maintenance Center and its warehouse. This means the array site will have a limited number of depots, garages, and storage buildings.

Items will be repaired offsite at a separate repair center, with "green-tagged" assets shuttled to and stored at the Maintenance Center. Shuttling of personnel from repair center to array will be minimized. Science, scientific and user support, and data analysis will be done remotely. Software support and research and development of hardware and software will likewise be done remotely.

In the following table, a breakdown is given of the type of work done and buildings and equipment needed for various locations of operations effort. It starts with the work to be done at the array and progressively moves further from the array. Continuously operated equipment and buildings are minimized at the site in lieu of a Maintenance Center and Remote Support Stations, while array operations, array maintenance, science operations, and support work are done at various locations further away.

At Array	Near Array	Within State	Anywhere
Personnel • On-shift security • Working O&M staff: techs, safety • Visitor's Center staff	Personnel • Safety • Security • Field Techs/Engs • Infrastructure Techs/Engs	Personnel • Operations • Administration • Repair Techs/Engs • Correlator Support • Computing Support • Safety	Personnel • Scientists • Administration • Data Analysis • User Support • Data Management • Software
Buildings • Central Electronics • Garage • Depot • Security • Visitor's Center (nearby)	Buildings • Maintenance Center (parts depot, work space, garages) • Remote Support Stations	Buildings • Repair Center • Operations Center	Buildings • Science Center • Research & Development
Equipment & Assets • Antennas • Correlator • Other Array Assets • Heavy equipment required at site at all time	Equipment & Assets • Spare LRU/Hardware • Vehicles • Equipment for testing, working on antenna, infrastructure, transferring parts	Equipment & Assets • Items under repair • Repair/test equipment • Vehicles for shuttling assets and staff	Equipment & Assets • R&D equipment • Data storage

6 Integration and Testing Centers

6.1 *Concept*

Electronic and other components will be directed to one of several integration and test centers, where they will be assembled into LRUs and tested in-house prior to being shipped to the warehouse for inventory and storage. These LRUs will be checked out of the central warehouse by the Antenna Integration and Verification group (AIV) for antenna assembly and acceptance testing.

6.2 *Assembly Centers*

Table 1 (next page) is self-explanatory. It lists seven integration and test lines, with the basic building requirements. Some of these lines are likely to be housed in the same structure. Of the seven integration lines, the Integrated Receiver Package, SA501, and Antenna Assembly locations are reasonably well understood. An additional facility or facilities for the remaining lines must be identified. It is possible one or more of these lines could be located in a leased structure, and possibly near a metropolitan center. This discussion will continue as the ngVLA construction and integration plan matures.

Center	Location	Size sf	# of Staff	Loading Docks	Clean Room Sq ft	RFI Chamber sf	Stock Room sf	Offices	Video Conf	ESD
Integrated Receiver Package	Charlottesville								accessible	
SA501	Socorro	15,000	15	2	2000	10X15 (2)	1000	5	1	50%
Power Supplies	Socorro	3000	3	1	-	-	1500	1	accessible	-
DBE/DTS, M&C		5000	6	1	1000			3	1	50%
WVR / weather staion		2000	2	1	1000	-	1000	3	accessible	80%
LO generator/ RTP		3000	4	1	3000	10X15 (1)	500	3	1	100%
Antenna Assembly	ngVLA				0	-		3	accessible	-

Table 1 – ngVLA assembly centers and building requirements.

6.2.1 Line 1: Integrated Receiver Package

The Integrated Receiver Package is being designed and developed at the NRAO Central Development Laboratory (CDL) in Charlottesville, Virginia. These assemblies will be manufactured out of house. They will be delivered to the CDL for testing prior to being transported to the SA501 (Front End) integration center in Socorro, NM.

6.2.2 Line 2: SA501

The Front End assembly (SA501) includes two dewars, six feeds, integrated receivers, and other electronics. The assembly and testing of the Front End subsystem requires a center of considerable size and sophistication, with 15,000 sq. ft. of floor space, 2,000 feet of clean room, and a stock room sufficient to collect and store the various components awaiting integration. Located in Socorro, completed and tested assemblies from this center will be transported by NRAO staff to the ngVLA Warehouse, where they will reside until antenna integration. The SA501 center is a prime candidate for re-purposing into an electronics repair lab after construction is complete. This building may be built as AUI/NRAO property, or it may be constructed by a local entity (New Mexico Tech or the City of Socorro) and leased to NRAO.

6.2.3 Line 3: Power Supplies

All power supplies will be ordered out of house. They could be installed into modules by NRAO staff, or this task could be outsourced to a third party. Regardless, they will be tested in Socorro. Upon acceptance, these will be transported to the ngVLA Warehouse for future integration into antennas.

6.2.4 Line 4: DBE/DTS, M&C

The Digital Back-End (DBE), Data Transmission System (DTS), and Monitor and Control (M&C) electronics will be manufactured out of house. Integration of printed circuit boards and other standalone components into LRUs may take place in Line 4, or at an off-site manufacturing house. Each unit will undergo acceptance testing prior to becoming part of the warehouse inventory.

6.2.5 Line 5: WVR/Weather Station

Water Vapor Radiometers (WVR) for each antennas along with approximately 65 weather stations will be manufactured and tested out of house before undergoing in-house acceptance testing.

6.2.6 Line 6: LO Generator/RTP

The Local Oscillator (LO) Generator and Round Trip Phase assemblies will be designed by staff at the NRAO CDL.

6.2.7 Line 7: Antenna Component Assembly

If a composite dish design is adopted by the project, these will likely be fabricated at the VLA site. Possible existing locations, after modifications, include the Antenna Assembly Building, the Transporter Shop, and the Track Building. The backing structure would be joined to the dish at the same location.

6.2.8 Antenna Integration

Assembly of the major antenna components (dish, pedestal, Front Ends, other electronics) will occur at each antenna pad.

6.2.9 Warehouse

Though not an integration center per se, the project warehouse is listed here for completeness. A warehouse sufficient to house components and LRUs during array construction and spares and consumables during operations is recommended to be built in reasonable proximity to the ngVLA. A portion of the warehouse must be climate controlled, as several of the electronic assemblies are susceptible to extreme temperatures.

7 Observatory Building Location Options

The ngVLA project presents the challenge of constructing and operating an array of 263 antennas. To support such a large array, many groups will find it necessary to work closely together. These groups will require substantial work areas/buildings capable of meeting the demands of both constructing and outfitting the array in the early stages and maintaining and servicing the array. The following describes the groups that will need workspace for the ngVLA project.

- **Electronics**: Responsible for outfitting and maintaining all Front End and electronics components in the array. They will need space to build, test and validate, maintain, and service all the components. Additionally, electronic technicians will be responsible for maintaining and servicing electrical aspects on the antenna. The electronics building must house staff and provide office workspace, a testing area, and a production space for ngVLA components.
- **Antenna Technicians**: Responsible for servicing and repairing antenna LRUs and mechanical components. This includes preventive maintenance on the entire array as well as repairing antennas as parts fail.
- **Servo**: Responsible for the antenna movement, including azimuth, elevation, and Front End receiver positioning. The servo group will need space to accommodate array maintenance and service. The servo building must house staff and provide office workspace, a testing area, and a production space for ngVLA components.
- **Cryogenics**: Responsible for the cryogenics systems on all the antennas. Each antenna will have six cryogenically cooled receivers. The cryogenics group must build, outfit, and maintain all the cryogenics systems for the entire array. The cryogenics building must house staff and provide office workspace, a testing area, and a production space for ngVLA components.
- **Computing and Information Services (CIS)**: Responsible for the installation and upkeep of the myriad computing resources necessary to support the ngVLA mission and the local NRAO community. At least a representative group of CIS staff should be located at the DSOC in Socorro.
- **Machine Shop**: Responsible for manufacturing ngVLA components and maintaining the site once it is up and running. Due to the remote location and system uniqueness, an in-house machine shop is required. The machine shop building must house staff and the machine shop area, to include Computer Numerical Control (CNC) and manual machines in support of both construction and maintenance activities for the ngVLA.
- **Auto Shop**: Responsible for maintaining and repairing all vehicles used to run and service the array. Due to the remote location and the heavy and light duty equipment that will be required, an in-house auto shop is required.
- **Grounds**: Responsible for maintaining roads and antenna areas on site. The grounds building must house staff and all equipment needed for antenna array grounds maintenance.
- **Electrical**: Responsible for all site low, medium, and high voltage electrical components. These include utility power distribution, backup generators, and site building and antenna power systems. This group will be responsible for maintaining all the site and building electrical systems, but will not be responsible for any buildings leased from outside entities.
- **HVAC**: Responsible for outfitting and maintaining the Heating, Ventilation, and Air Conditioning (HVAC) units for all array antennas. The group is also responsible for maintaining the HVAC for all site buildings, but not any buildings leased from other entities. Members of this group may be seconded to the support of site water and sewer facilities.
- **ES&S**: Environmental, Safety, and Security personnel are responsible for coordination and implementation of safety and health best practices and to support all staff with regard to all safety and health programs.

7.1 Option 1: Use Existing JVLA and DSOC Facilities, with Necessary Upgrades

This option proposes to upgrade and repurpose the current JVLA site and DSOC facilities to accommodate the ngVLA project. The VLA site infrastructure and buildings will be upgraded and refurbished as necessary to support ngVLA. This would include renovating all site buildings, bringing them up to code and performing necessary upgrades to extend their life to meet that of the ngVLA.

This option would most likely include some new construction to accommodate the scale of the ngVLA as well as facilitate the transition period. The JVLA is expected to operate during the transition period. The current site buildings will be close to 40 years old at the start of ngVLA construction and will have to be upgraded to extend the lifespan no less than an additional 20 years. The control building along with metal workshops will have to be updated to current code in respect to both building structure and ADA and OSHA standards.

Under this option, the personnel located at the ngVLA site will mirror that of the current VLA. The technical services including Machine Shop, HVAC, Electricians, ES&S, Antenna Technicians (Antenna Mechanics, Servo Cryogenics), Warehouse, and the Auto Shop will all be located at the central site. All support vehicles and equipment would be at the central site location.

7.1.1 RFI

Radio Frequency Interference (RFI) is a major concern going forward with ngVLA as more electronic devices are dependent on Bluetooth and Wi-Fi, including vehicles. Locating all the maintenance and repair centers on site would most definitely introduce unwanted RFI. RFI generated close to the central core would have a detrimental impact on the science for the array.

Having a Visitors Center close to the core would also introduce a major RFI risk. Newer vehicles are equipped with Bluetooth, Wi-Fi, and other new technologies such as self-driving capability. These new vehicle technologies would jeopardize the quality of science if these vehicles were positioned near the array center. The visitors themselves also present RFI issues with smartphones and other Bluetooth devices such as smart watches, health monitors, and headphones. The simple fact is that if anyone with any emitting electronic device visits the center core, the science for the duration of their presence would be compromised. RFI and its potential effects on the operation of the ngVLA are explored in [RD02], ngVLA Radio Frequency Interference Forecast.

7.1.2 Integration Centers

Reutilizing the VLA site would require separate integration centers where new antenna components could be stored and assembled. The magnitude of this project would require renting or building large production facilities to accommodate building necessary components to outfit the large number of antennas. The DSOC is not currently capable of supporting a project the size of ngVLA. A production-oriented facility with loading docks and ample workspace will be required. It may be possible to rent space in the Socorro area, but availability may be an issue and will most likely require new construction to meet our needs. After ngVLA construction and antenna outfitting are complete, under this scheme the integration centers would no longer be needed.

7.1.3 Transition Plan

As described in [RD04], ngVLA Transition Concept, the prevailing concept is to keep the current VLA operational until ngVLA is at least partially online. However, the option of re-using the current VLA facility during the transition would be very difficult, if not impossible. If the control building were to be repurposed and used to house the new processor, it would be a wiring and communications nightmare to have both systems running simultaneously. The existing control building would have to be wired for ngVLA power and fiber, while not disturbing the old infrastructure. Furthermore, the control building would have to undergo a tremendous amount of destructive renovations to bring it up to current codes and standards. The building would likely be rendered useless for science during these upgrades.

7.1.4 Travel

The site work structure would mirror that of the current VLA. Employees would arrive to the VLA site as their home work station. The workers would then perform work as required on the array. As with the current VLA operations, buses would run from Socorro and Magdalena to the site. The number of buses would necessarily be increased as the number of employees increases for ngVLA.

7.1.5 Infrastructure

A perceived advantage of reusing the existing site is the ability to reuse, to a degree, the current VLA infrastructure, roads, sewer, buildings, etc. within the current square mile on which the VLA resides.

7.2 Option 2: Staff Housed Between Socorro, Magdalena, and the ngVLA site

To minimize staff at the ngVLA site, it has been proposed to construct an offsite campus close enough to house specific technical services for the array, but far enough away so that RFI would not be a concern.

Magdalena, NM is the ideal location for the second campus. It is located 24 miles from the current VLA and 27 miles from the DSOC. With this concept, the DSOC remains an integral location and will house the Electronics Division along with other observatory support staff. The breakdown for personnel located at each site is provided below.

7.2.1 Socorro (DSOC)

Science, computing, electronics, and administrative support staff will be located in Socorro at the DSOC or possibly a newly constructed building. This model is similar to the current VLA operations that are located at the DSOC. High-level repairs would be sent to Socorro from the ngVLA site. The Electronics Division would make the repairs to Front End and LO/IF modules, then ship them to the Magdalena campus for storage until needed. The Socorro group would be responsible for higher-level repair and testing, while simpler repairs would be done at the Magdalena facility.

Depending on staffing requirements, an addition to the existing DSOC facility or totally new construction may be necessary. This would require a modification to the land agreement with New Mexico Tech if it is decided to expand the DSOC. If science and computing are relocated to another location, the space freed up could be used for more lab space, which may make the current building size adequate. Additionally, if the current VLBA is replaced by ngVLA and the DSOC is not needed to house the VLBA correlator, support staff, and facilities, this area also becomes available for ngVLA operations, support, and overhead staff.

7.2.2 Magdalena Area

Technical services including Cryogenics, Machine Shop, Servo, HVAC, Electricians, ES&S, Antenna Technicians, the main Warehouse, and possibly the Auto Shop would be located in the Magdalena area. Essentially the idea here is to pack up the current VLA model and move it to Magdalena with a few exceptions. The technical staff would be stationed at the Magdalena campus and would perform maintenance and repairs on the antenna components on site. For maintenance or repair that requires an antenna visit, the technicians stationed in Magdalena would travel directly to the affected antenna, without necessarily needing to travel to the central site.

7.2.3 ngVLA Site

In the effort to have a minimum of full-time staff located at the site, only security guards and possibly ES&S representatives will be a constant presence at the ngVLA site. Transient staff including the operator and auto mechanics would only be at the site as required. The main building at the site would be the processor building, which would house the processor and all required on-site computing. This building would be constructed as an RFI-tight building, and possibly underground. It would house a few offices and a conference area to facilitate on-site meetings and support during the transition period.

Generators for site backup power will be at the central site near the processor building. An auto shop would need to be on site to facilitate maintenance and repairs to the site vehicles and equipment, some of which are very large. A vehicle depot housing all maintenance vehicles and heavy equipment would also be located at the central site. As with the current JVLA, an RFI testing chamber could be located at the central site, but could also be built in Magdalena.

Moving the majority of operations off site does not necessarily mean the existing buildings will be demolished. The existing metal buildings, including tech services, warehouse, auto shop/servo building, and track shop may be used as cold storage or remote warehouses, in addition to construction centers for the new antennas. One of these buildings could alternatively be repurposed or expanded to accommodate a new auto shop. The antenna barn can also be used as an auto depot for maintenance vehicles. Buildings that cannot be reused or repurposed would ultimately have to be demolished as part of any planned JVLA decommissioning effort.

7.2.4 RFI

The greatest observing and science benefit of this option would be the elimination of almost all RFI introduced by staff and computing. By removing the maximum personnel from the site, automobile and computer emissions or the risk of a device such as a cell phone being inadvertently left on is greatly reduced, if not altogether eliminated. Technical services requiring electronic equipment would not have to worry about noise created if they are not on site. It would be much more difficult to deal with RFI with the ngVLA center core being so congested with antennas. Per [RD02], reducing RFI must be a priority in the design and construction of the new array.

7.2.5 Integration Centers

The opportunity to have all new construction for the majority of ngVLA support buildings has a built-in advantage for integration centers. The new buildings can be designed to act as integration centers for the ngVLA construction and antenna outfitting, then modified for steady state operations and maintenance. The buildings would be built as production facilities and transition into support facilities as construction ends. The integration centers can be built in Magdalena and later transition into antenna support buildings there as well as Socorro. One could also transition into an electronics support location.

7.2.6 Transition Plan

A transition plan would allow for the JVLA to operate at some level until the ngVLA is up to a minimal operational state. Depending on the determined site of the central core of antennas, the current JVLA building configuration may adversely affect the way power and fiber are routed to the new array.

7.2.7 Travel

The site work structure would somewhat mirror that of the current VLA. Employees would arrive to the Socorro and Magdalena locations as their home work station. Each day the staff in Magdalena would receive assignments and then travel to the main site to perform work as required on the array. As with the current VLA operations, buses or perhaps vans could transport remote staff assigned to the Magdalena campus. From the Magdalena campus, workers would only go to central site if repairs or maintenance are required. Likely they would travel as teams in company vehicles to the equipment depot, where they would transfer to a larger vehicle capable of servicing the antennas.

7.2.7.1 Infrastructure

At the ngVLA site, portions of the existing VLA infrastructure, roads, sewer, buildings, etc., could be reused for the processor building where appropriate. New infrastructure (electrical, communications, water, and sewer) will necessarily be new construction for any production and maintenance facilities built in Magdalena.

7.3 Option 3: Science/Computer Operations Staff Located in Major Metropolitan Center

This option would potentially allow for easier employee recruitment and retention and, if the city were an airline hub, could streamline travel. An office building would be leased in a major metropolitan center. For this reference study, Phoenix, Dallas, and Denver are used as examples. Moving these staff away from Socorro would free up many of the offices at the DSOC. The new space at the DSOC would allow for additional room for overhead staff as well as electronics and engineering offices. This option can be realized with either upgrading the existing JVLA site structures or by the construction of new facilities away from the site.

7.4 Option 4: Remote Support Station Option

The far-lying antennas will be far away enough that maintenance from the central site would require constant travel and lodging for the service technicians. In some cases, this could be problematic in that long travel distances could be required, and overnight lodging could be difficult to locate.

One option to avoid this is to place remote support stations near clusters of far-lying antennas. The idea is similar to the VLBA sites, providing a work location with all required equipment on site. Depending on the final configuration plan for the mid-baseline antennas, four to six regional stations with four to six site technicians each would be stationed in towns nearest to a cluster of remote antenna. The number of these support stations will in part be determined by the distance between the station and each antenna within the region. Travel to and from an antenna, in addition to the work performed, would ideally be completed in one day.

The site technicians would be responsible for coordinating with the warehouse for replacement LRUs, and maintaining and servicing the remote antennas in their assigned region. The stations would consist of office space, a repair area, nominal storage space, and restroom facilities. Establishing these remote stations rather than relying on long travel routes for antenna maintenance technicians is highly recommended. It will remain an option to include these facilities regardless of the decision whether to include the stations in the baseline construction plan.

8 Assessment of Current Facilities

8.1 VLA Buildings and Utility Infrastructure

The existing buildings and infrastructure at the central VLA site have been serving the observatory for over 40 years, and though well maintained, they are naturally showing their age. To better determine if these structures are candidates for renovation and upgrading, NRAO contracted the engineering firm Bohannan Huston to perform a high-level site building and infrastructure assessment. The purpose of this study is to evaluate the suitability of the current facilities and infrastructure for ngVLA use. A brief summary is provided in the sections below. The full report is provided as [AD03], Bohannan Huston JVLA Site Assessment.

8.1.1 Buildings

The site buildings evaluated for this study include the two-story brick Control Building and the pre-fabricated metal Warehouse, Technical Services, Track, Generator, Carpentry, Auto/Electrical Shop, and Antenna Barn buildings.

The Control Building, erected in 1975, was determined to be in overall good condition. However, if major renovation to the building were to occur, the standards to which the building were originally constructed would no longer be applicable. Several improvements would be required to bring the building into compliance with current American with Disabilities Act (ADA) standards. Structurally, the Control Building is sound, though extensive structural efforts would be required to modify the elevator core and the access areas. The mechanical and electrical systems in the building are in good condition and have undergone consistent and routine maintenance, but all are original and would be likely targets for replacement, with the exception of the newly installed main electrical panel. Plumbing fixtures are older and in fair condition. Finally, it was noted that most of the Cat 5 technology wiring in the building is unshielded and provides a source for EMI emissions.

Based on the Bohannan Huston observations of the existing control building, it is our opinion that the current building will not adequately serve the needs of the proposed expansion due to substantial reconfiguration of the current floor plans needed to meet current Building Code and Accessibility requirements as well as upgrades and replacements of the mechanical and electrical systems. Performing the required renovations and upgrades on the existing structure will be met with limitations that may hinder the facility from reaching its complete, planned potential in support of ngVLA.

The site's pre-fabricated metal buildings appear structurally sound. At present, an initiative is underway to replace the exterior windows and doors. Should the buildings be called into future service, new exterior skins should be considered. The electrical systems are a combination of original and upgraded sections. Most of the HVAC systems have been upgraded over the past decade.

Potable water is available at all facilities at the VLA via an onsite closed-loop system. The facilities are supplied by a groundwater well that pumps into a 30,000-gallon above-ground steel storage tank. The distribution system piping varies in size and material type depending on its location. Piping has been reliable with minimal leaks and repairs. The fire pump is rated for 1,000 gal/min and has been recently upgraded with a new controller unit. Although adequate for their current use, upgrades to the domestic water system will be needed to meet the 50-year expectancy of the proposed facility.

The onsite sanitary sewer system consists of a gravity collections system that serves the control building, visitor center, and most of the other site buildings. This collection system drains to a lift station that then transports waste water to a two-cell facultative lagoon system for processing and disposal. The lagoons are in good condition and are adequate to provide service for the future facility, though they may have to be modified to a more appropriate size depending on the expected site occupancy. The sewage lift station is in good condition, but it has been identified as needing to be replaced to meet code requirements and provide better efficiency. The existing collection system is in good condition. Without additional lift stations, the extent of service that can be provided to the site buildings is limited by the site topography. The ability to connect new buildings that may be a part of the proposed expansion to the current gravity system will be location-dependent.

8.2 JVLA Antenna Pads

Once the ngVLA is in an operational state, the old JVLA will require decommissioning, while the old site buildings will either be upgraded and repurposed, or demolished. The current thought process is that all JVLA antenna pads will be removed to just below ground level. The current ngVLA antenna design does not follow the same configuration of the existing array, nor does it fit the JVLA antenna footprint. Furthermore, repurposing the piers will complicate foundation design. Additionally, the current design does not have any antennas located at the current antenna pad locations. Finally, by not utilizing the current VLA pads, this allows for the VLA to continue to operate during ngVLA construction.

8.3 Domenici Science Operations Center

The Domenici Science Operations Center (DSOC), located on the campus of New Mexico Tech (NMT) in Socorro, NM, is home to the offices and labs that support JVLA and VLBA operations. Scientific, Computing, Engineering, Fiscal, and Human Resources staff are located in this building. Most NRAO New Mexico staff are stationed here. NRAO has a 99-year lease on the building at virtually no cost. However, NRAO pays NMT $280K/year for maintenance services.

The DSOC as it is currently configured will not support the electronics division staff needed for ngVLA. The basement is not suited for any of the large-scale production lines that will be needed for building and testing ngVLA assemblies. The building does not have a proper loading dock to receive and ship components and assemblies, or to allow for reasonable transportation of the larger LRUs. For this reason, we believe a larger, more production-oriented electronics integration and repair center is needed. The DSOC, however, remains well suited to house Operations, Administration, Correlator Support, Computing Support, Safety, and some engineering support other than what is proposed to be located in the new electronics repair facility.

If the electronics division were to move out of the DSOC, as is our recommendation, the entire area could be remodeled into office space for additional staffing numbers required by ngVLA. The current VLBA operations and correlator area can also be remodeled to accommodate more office area. In addition to the electronics support groups, the correlator engineering support group that currently resides at the DSOC would also move to the new electronics repair facility.

9 Reference Design

The ngVLA Reference Design is described and estimates are provided in this section. The reference design is based on the needs of the project, the operations concept, environmental concerns, and economics. It is our opinion that options 2, 3, and 4, as defined in Sections 7.2, 7.3, and 7.4, will best serve the ngVLA.

9.1 Site Electrical Infrastructure

9.1.1 Assumptions

The ngVLA will use the existing utility feed from Socorro Electric Cooperative. Total power consumption of all ngVLA antennas will be similar to the total power consumption of existing JVLA antennas. Correlator power consumption will be similar. Office and industrial loads will be mostly located outside the array site. System reliability is prioritized as high. Remote antennas will be no more than one mile from existing electrical grid components.

9.1.2 Goals

Primary goals include minimizing system downtime for preventive maintenance, eliminating all single-point failures during regular operations, and minimizing single-point failures during preventative maintenance.

9.1.3 System Description

9.1.3.1 Plains Array

9.1.3.1.1 Design

The electrical grid proposed by this document follows a circular distribution model (see Figure 1). To this end, the backbone consists of multiple switchgear enclosures, each with at least two power sources. This level of redundancy allows for individual components of the grid to be removed for maintenance with minimal impact to site performance. The specific level of impact varies depending on the placement and function of each switchgear cabinet, and will be discussed further on.

As a point of comparison, the existing JVLA uses a centralized distribution model. At the present site, all loads can be traced back to a single distribution switchgear. This necessitates that any maintenance to this central piece of switchgear requires the array to go dark.

The ngVLA grid will be supported by three generators. Two will be rated as prime sources, and one rated for emergency backup. While all three generators are expected to be utilized in a backup capacity, generators rated as prime sources meet more stringent environmental regulations and are capable of prolonged operation. The two prime sources will each support one of the main branches, the CW (clockwise) and CCW (counter clockwise) busses.

The third generator will be connected to both of the main branches via interlocked disconnects. As configured, it may be connected in the place of either prime source while one is down for maintenance or testing. For purposes of conservative budgeting, all three generators have been costed out to be capable of powering the entire ngVLA Plains Array. As design details become more fleshed out, the prime source rated generators will most likely approach a rating of two-thirds the total site load.

This reference design includes five switchgear cabinets to supply major site loads. Four of these switchgear cabinets will supply antennas in chains of approximately five. The fifth cabinet will provide power to both the new processor and various support buildings.

Figure 1 (next page) illustrates the main electrical grid components for the ngVLA central site.

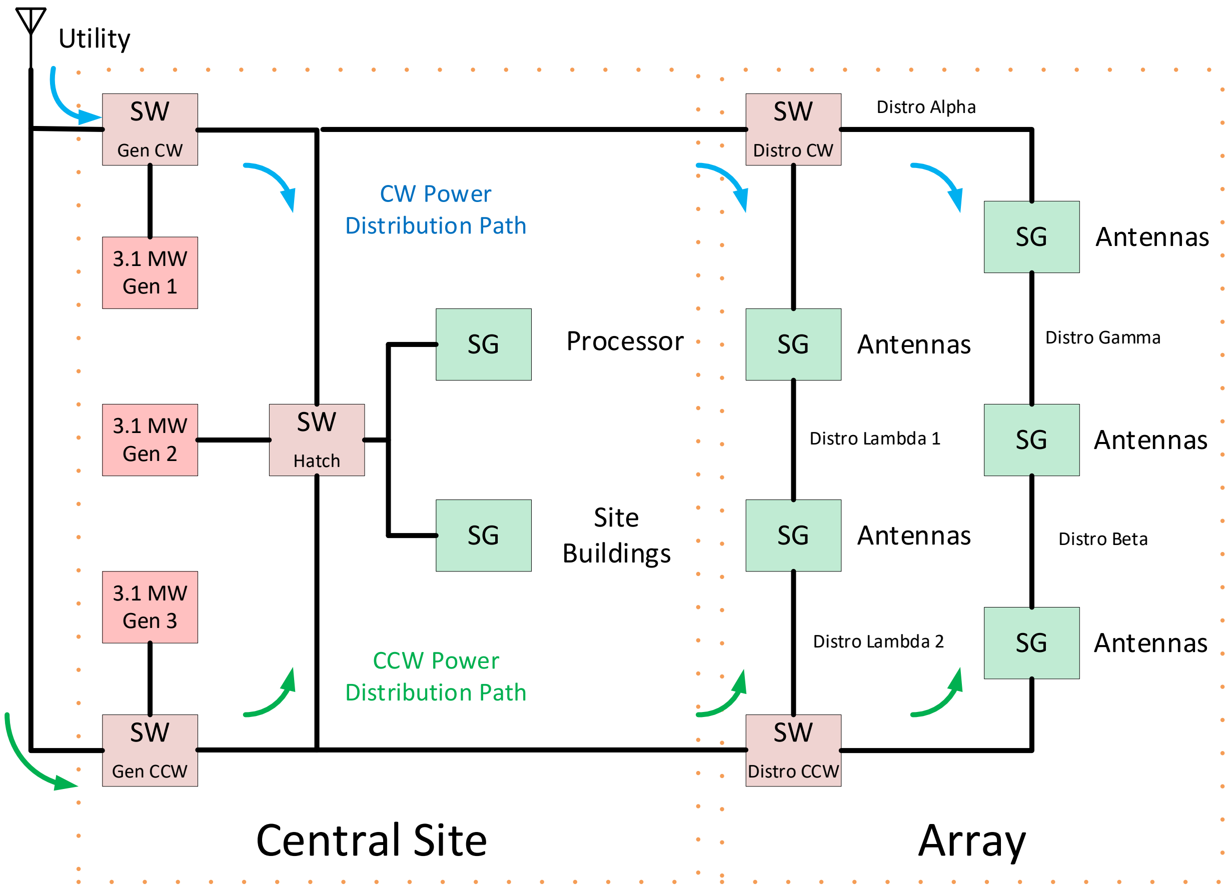

Figure 1 - ngVLA central site electrical grid components.

9.1.3.1.2 Construction

Current expectations are for the ngVLA to be centered slightly northwest of the existing JVLA. This placement seeks to minimize interference with JVLA operations prior to ngVLA coming online. To shorten construction schedules and support other ngVLA construction and testing efforts, NRAO proposes that the following electrical infrastructure components be prioritized for installation:

- High priority
  - Hatch_Gear
  - Generator_Gear_CW or Generator_Gear_CCW
  - Processor_Xform
  - TS_Xform
  - Utility_Xformer

- Moderate priority
  - Trenching
  - Concrete foundations

- Low priority
  - Distribution switchgear
  - Low voltage infrastructure

Completing the high-priority items, along with the power cabling to interconnect them, will provide medium voltage power to all array support facilities. This provides two benefits throughout ngVLA construction. As electronic systems are installed, power will be available for testing. Initially this will be limited to the processor and networking systems, but as the remaining electrical switchgear is set in place, field testing of antennas is possible without relying on large numbers of portable generators. The second benefit is that having workshops and storage spaces on site provides a staging facility throughout the construction process.

Trenching and concrete foundations follow in the proposed list of priorities. This is largely due to the interference between trenching operations and access roads. Given the scattered and disjointed arrangement of antenna groupings, trenches will frequently cross convenient roadways to limit conflicts between trenching efforts and logistics around the construction site.

The concrete foundations are included in this subset as they must be at both ends of a trench to allow power cables to be pulled and their terminations protected. Trenching operations will also be coordinated with installation of fiber optics and any other data connections throughout the array. Doing so will minimize duplication of effort when trenching. The electrical power grid infrastructure for the core and plains portions of the ngVLA are provided in [RD05], ngVLA Core and Plains Power Infrastructure.

9.1.3.2 Remote Array

9.1.3.2.1 Design

Remote ngVLA antenna sites fall into two classifications, new and existing. Existing remote antenna sites are anticipated to use existing VLBA infrastructure or its equivalent, whereas new remote antenna sites will be constructed from the ground up. In either case, these sites will be supplied with a single switchgear enclosure, a transformer per antenna, and a temporary generator connection point.

The current remote locations of the VLBA are supported by backup power generators. These will not be used to support ngVLA remote antennas at existing remote sites. Neither will backup generators be implemented for new remote antenna locations. Rather, remote antenna locations will rely solely on local power infrastructure to operate.

For VLBA sites, it is unlikely that existing backup power can support additional large loads, although this may be revisited once power requirements become more tightly defined. At the new remote sites, to do otherwise would require frequent trips to each remote site to perform preventive maintenance and inspections on both the generators and their associated fuel storage facilities.

Limited backup power will be supplied to each individual antenna via a UPS system. This power source will be sufficient to stow the antenna and gracefully shutdown electrical systems. The UPS system is considered an internal component to the antenna, and is not discussed in this document.

Utility power will be supplied to new remote antenna sites via a single low-voltage switchgear cabinet. These enclosures will contain three breakers and a multi-function relay. In addition to these basic components, remote ngVLA switchgear units will tie into the Supervisory Control and Data Acquisition (SCADA) system for the entire array. In the case of existing antenna locations, this switchgear cabinet will include additional breakers for every additional ngVLA antenna collocated with the first.

Qualified personnel will have access to view data pertaining to current power quality and status. Qualified personnel will also have the ability to operate the breaker in order to remove and apply utility power to the antenna. This is expected to be a desirable feature in order to allow hard resetting of antenna systems in order to clear potential faults, rather than dispatching repair crews.

Each site will be provided with a connection point for installation of a temporary generator. This will allow teams dispatched to the antenna site to power up the antenna in the event that reliable utility power is unavailable at the time of work being performed.

9.1.3.2.2 Construction

Construction of the remote sites may be accomplished independently of one another and of the plains array. Installation of electrical infrastructure at these sites is a relatively simple endeavor, compared to the number of teams and systems to be involved in the plains array.

Unlike the plains array, electrical work at the remote sites can be accomplished independently from other construction tasks. The point to point nature of a remote site's connection to utility power allows cabling to run parallel to access roads, avoiding disruption in regards to which is created first. Furthermore, the small number of components involved drives a work schedule with very low scheduling risk.

9.1.4 System Behaviors

9.1.4.1 Normal Operation

Referring to Figure 1, during normal operations the site will be fed by utility power through both the clockwise (CW) and counter clockwise (CCW) generator buses. Loads will be shared in approximately equal division between the CW and CCW buses. Generators 1 and 3 will be on standby ready to transition power.

9.1.4.2 System Fault Response

In the event of a system fault, trained array staff will be able to reroute power through the grid to remove the impacted components. Where possible, these transitions will be automated to minimize impact to array observations. When automatic transitions are not possible or the automated response leaves the array in an impacted state, trained NRAO electrical staff will be relied upon to manually transition the array to an optimal configuration.

All array antennas will rely upon local UPS systems to maintain power during electrical grid configuration changes. With the exception of switchgear feeding 480 volt loads, there is no impact. The impact to the array's performance due to faults in other busses varies throughout the system.

Table 2 (next pages) identifies the effects of faults throughout the ngVLA electrical distribution system. Events in the first protective action and second protective action columns are automatic system responses. The array impact column identifies the worst-case loss of function following the automated response. Short-term and long-term corrective actions identify actions taken by site personnel to mitigate and eventually correct the system impact.

Fault Location	1st Protective Action	2nd Protective Action	Array Impact	Short Term Corrective Action	Long Term Corrective Action	After Hours Call-Out Required?
Processor Switchgear Load	Upstream Breaker Trips		Drop Processor Load	Remove faulted load	Replace faulted load	Consider
Processor Switchgear	Upstream Breaker Trips		Drop Processor	If breaker, replace	Develop corrective maintenance plan	Yes
Tech Services Switchgear Load	Upstream Breaker Trips		Drop non-essential load	Remove faulted load	Replace faulted load	No
Tech Services Switchgear	Upstream Breaker Trips		Drop all non-essential load	If breaker, replace	Develop corrective maintenance plan	Consider
Hatch	Upstream Breaker Trips		Drop processor and all non-essential load	If breaker, replace	Develop corrective maintenance plan	Yes
Distro CW	Upstream Breaker Trips	Re-route power through Distro CCW and Distro Gamma	None	If breaker, replace	Develop corrective maintenance plan	No
Distro CCW	Upstream Breaker Trips	Re-route power through Distro CW and Distro Gamma	None	If breaker, replace	Develop corrective maintenance plan	No
Distro Alpha	Upstream Breaker Trips	Re-route power through Distro Beta as necessary	Drop 30 Core Antennas	If breaker, replace	Develop corrective maintenance plan	Consider
Distro Beta	Upstream Breaker Trips	Re-route power through Distro Alpha as necessary	Drop 30 Core Antennas	If breaker, replace	Develop corrective maintenance plan	Consider

Fault Location	1st Protective Action	2nd Protective Action	Array Impact	Short Term Corrective Action	Long Term Corrective Action	After Hours Call-Out Required?
Distro Gamma	Upstream Breaker Trips		Drop 30 Core Antennas	If breaker, replace	Develop corrective maintenance plan	Consider
Distro Lambda 1	Upstream Breaker Trips		Drop 36 Arm Antennas	If breaker, replace	Develop corrective maintenance plan	Consider
Distro Lambda 2	Upstream Breaker Trips		Drop 24 Arm Antennas	If breaker, replace	Develop corrective maintenance plan	Consider
Generator Gear CW	Upstream Breaker Trips	Re-route power through Generator Gear CCW	None	If breaker, replace	Develop corrective maintenance plan	No
Generator Gear CCW	Upstream Breaker Trips	Re-route power through Generator Gear CW	None	If breaker, replace	Develop corrective maintenance plan	No
208 VAC Antenna Load	Upstream Breaker Trips		Drop single antenna	Remove faulted load	Replace faulted load	No
480 VAC Antenna Chain Component	Upstream Breaker Trips		Drop six antennas	Open disconnect	Repair fault	Consider
Generator1	Generator Breaker trips	Generator 2 starts and routes power through Hatch	None	None	Develop corrective maintenance plan	No
Generator3	Generator Breaker trips	Generator 2 starts and routes power through Hatch	None	None	Develop corrective maintenance plan	No

Table 2 - Impact of single-system faults.

9.1.5 System Components and Costs

9.1.5.1 Plains Array

Component	# Needed	Cost
MV Breakers	62	
Switchgear Buses	11	$4.7M[1]
MV Transformers:		$3.5M[2]
1MVA	2	
650kVA	5	
100kVA	90	
50kVA	66	
LV Breakers and Enclosures	197	$2M
Cable Trenching		$31M[3]
Generators		$6M[4]
Total Cost		**$47.2M**

Table notes:
1. Based on EIU quotes, scaled by number of medium voltage breakers.
2. Based on vendor ROM pricing.
3. Based on recent contracted cable installation.
4. Based on EIU quotes and doubled to encompass construction of fuel storage and supporting infrastructure.

9.1.5.2 Remote Antennas

Component	# Needed	Cost
New Antenna Sites:		
MV Breakers	46	
Switchgear Buses	46	$4.6M
MV Transformers	46	$460,000
LV Breakers	138	
Existing Antenna Sites:		
Switchgear Buses	30	$3M
MV Transformers	30	$300,000
LV Breakers	50	
Cable Trenching	76 sites	$7.6M
Total Cost		**$15.96M**

9.1.5.3 Total Costs

Plains Array	$47.2M
Remote Antennas	$16M
Electrical Grid	$63.2M

9.1.6 Lifecycle Support

Electrical maintenance performed at the JVLA is largely corrective in nature. This is due in part to the age of the facility. This is exemplified by the faulty performance of the Hatch switchgear and generator sets that prompted the Electrical Infrastructure Upgrade (EIU) project. The nature of the JVLA as a collection of antennas periodically relocated also adds to this. Ultimately, the largest contribution to this approach is the impact to array performance caused by any maintenance operations.

For any given JVLAconfiguration, antenna feeders are either disused or vital to array operations. In the former case, this prevents data collection to predict future maintenance needs. In the latter case, this magnifies the impact of de-energizing the circuit by exercising mechanical components or in order to conduct repairs. Work that drops an arm of the array prohibits observing. De-energizing a single antenna deactivates almost 4% of the array. Dropping the distribution switchgear deactivates the entire array.

By comparison, the vast majority of maintenance, both preventative and corrective, performed on the proposed ngVLA will have minimal impact. The number of antennas reduces the impact of dropping a single antenna to less than 1%. Table 3 offers a comparison of impacts related to performing maintenance on various regions of the array.

Component Level	% of JVLA Array Impacted	% of ngVLA Array Impacted
Antenna	3.7%	0.4%
Antenna Chain	33%	2%–4.5%
Switchgear	100%	0%–13.6%
Correlator/Processor Switchgear	100%	100%
Generator	Loss of backup power	No impact

Table 3 - Comparison of maintenance impact on array regions.

Due to the impact of removing an antenna from the JVLA array for maintenance, great effort is taken to conduct all maintenance simultaneously and in as short a time as possible. This leads to tighter scheduling needs and a tendency to schedule work based on availability rather than functional priorities. The much smaller impact of removing an antenna from the ngVLA allows for maintenance to be scheduled independently of other tasks, exclusively by level of importance.

One of the more common corrective maintenance issues at the JVLA involves replacement of the plugs and jacks used to disconnect and reconnect antennas to their pedestals. These connection points tend to wear and rust during periods of disuse, both while connected or disconnected. The fixed nature of the ngVLA antennas will completely eliminate this issue.

Another facet improved by the lack of physical alterations to array configuration is that it will be possible to monitor all system components throughout the year. At the JVLA, the majority of transformers and disconnect switches are unloaded, limiting the usefulness of thermal scans in documenting component degradation. This increase in available data is expected to improve the ability of staff to better coordinate repairs.

Preventive maintenance, in the form of testing and inspections, will be conducted on a rolling basis throughout the array. It is intended that every component of the electrical grid, within the plains array, will be inspected either every three or six months. Components requiring regular exercising will be operated on a similar schedule. All remote antennas will be inspected and maintained on an annual basis.

9.2 Antenna Pads

9.2.1 Pad Design

The 18-meter antennas will require a substantial foundation to meet the stability requirements of the ngVLA. The initial loading requirements are listed in Table 4 and detailed in the foundation interface drawings shown in Figure 2, Figure 3, and Figure 4.

	Axial lb	Radial lb	Torsion lb*ft	Tipping lb*ft
Wind Load	16,636	29,293	133,572	1,696,393
Static Load	225,035	0	0	501
	X(ft)	Y(ft)	Z(ft)	
Load Placement ft	–1.64	0.00	41.01	
Foundation Natural Frequency (Hz)	8			

Table 4 - Initial loading requirements for 18-meter ngVLA antenna foundations.

The reference design for the antenna foundation consists of a 25' x 25' base pad 4' deep. The base pad will have four 4' diameter piles extending down 30' into the earth. A 3' x 3' grade beam will tie the antenna foundation to the piers and strengthen the foundation overall. Final antenna specifications and interface will be needed for the final antenna foundation conceptual design.

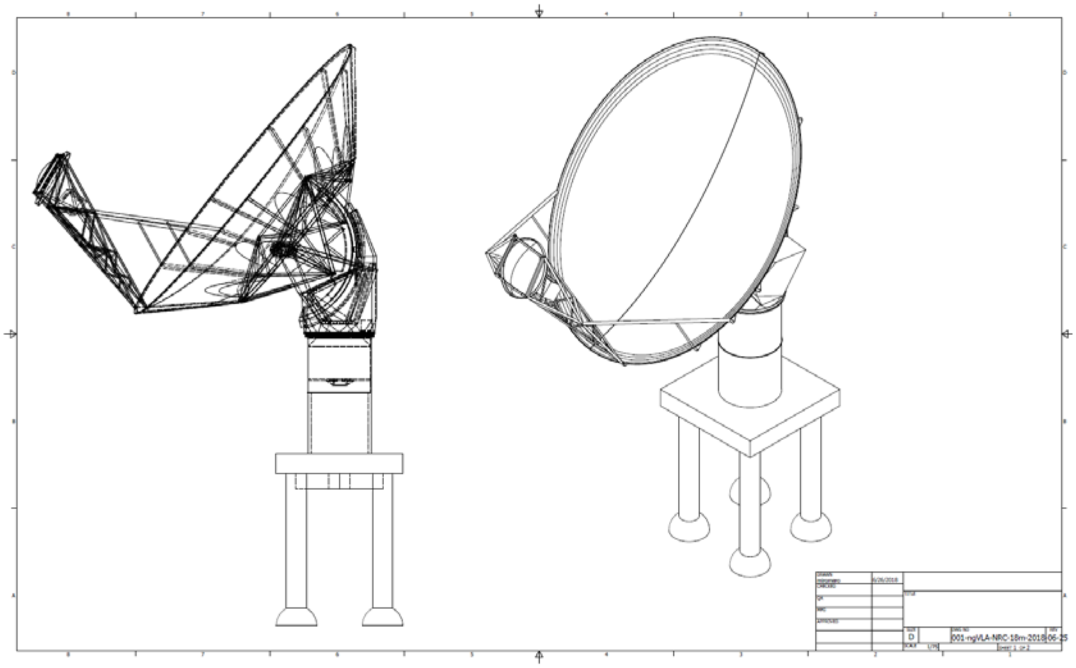

Figure 2 - Antenna foundation supports. Note that site grade is level with the pad, and the piles extend below grade.

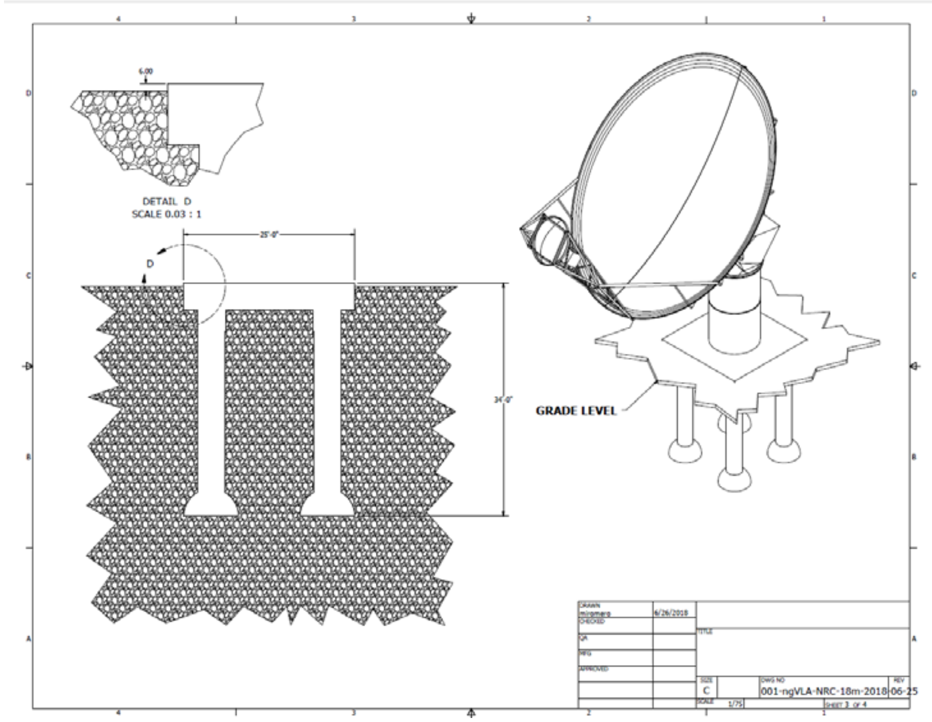

Figure 3 - Antenna foundation placement in concrete.

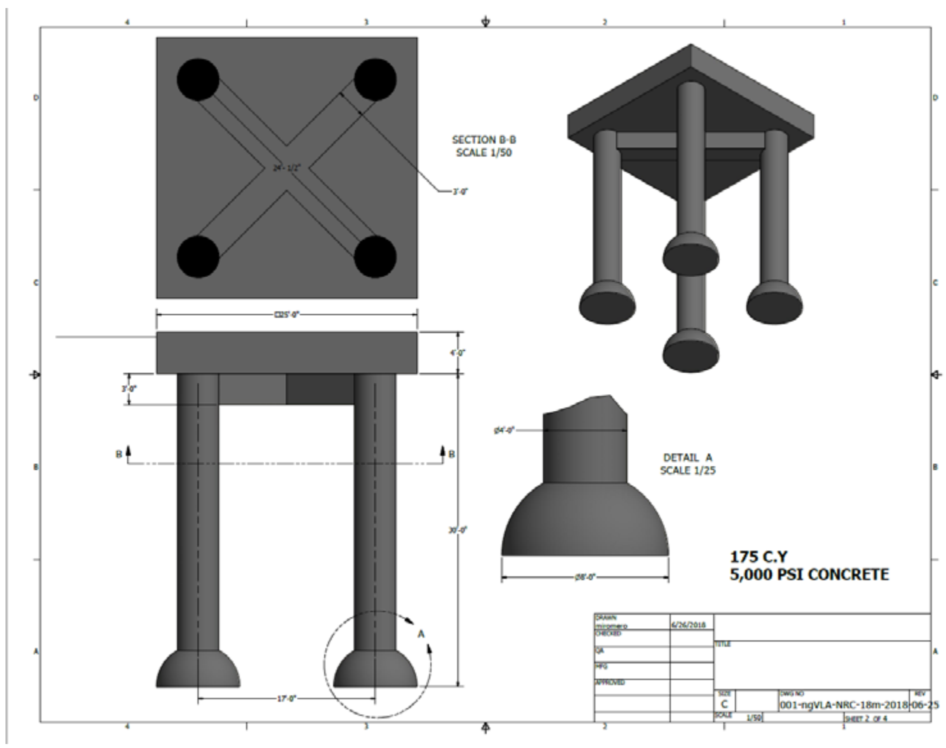

Figure 4 - Antenna foundation specifications.

Table 5 and Table 6 provide antenna foundation costing based on 2018 RSMeans data.

ngVLA Antenna Foundation Cost Estimate										
PILES										
	RSMeans REF	Diameter	L.F	QTY:			Volume C.Y		Costing	Sub Total
Drill Concrete Piles, each	31 63 26.13 0500	4	30				13.96		$134.00	$4,020.00
Bell Piles	31 63 26.13 1080	8		1			4.96		$3,575.00	$3,575.00
75 LB/C.Y Reinforcement	31 63 26.13 4300						18.93		$34.75	$657.72
Load and Haul Excavation, bore	31 63 26.13 4500						18.93		$6.45	$572.08
Load and Haul Excavation	31 23 23.20 1084						18.93		$19.20	$813.40
Pile Sub Total										**$7,595.00**
4 Piles										$30,380.00
Mobilization Each Location	31 63 26.13 4650			1						$3,925.00
Pile Total				4						**$34,305.00**
PILE CAP/BASE SLAB With GRADE BEAM										
	REF	Width F.	Length F.	Height F.	Ea	L.F.	Tons	Volume C.Y	Costing	Sub Total
Slab Concrete, 5000 psi	03 31 13.35 0400	25	25	4				92.59	$148.00	$13,703.70
Grade Beam Concrete, 5000 psi	03 31 13.35 0400	3	24	3				16.00	$148.00	$2,368.00
Forming (SFCA)	03 11 13.40 0020					400			$25.50	$10,200.00
Mobilization Each Location	01 54 36.50 1500				1				$960.00	$960.00
Remote Mobilization Cost	01 54 36.50 2500				5				$96.00	$480.00
Excavation	31 23 16.42 0250							135.74	$2.14	$290.49
Load and Haul Excavation	31 23 23.20 1084							135.74	$19.20	$2,606.22
Placing Concrete	03 31 13.70 1600							108.59	$28.50	$3,094.89
Placing ReBar (75lb/CY)	03 21 11.60 0600						4.07		$2,200.00	$8,958.89
Slab total										**$42,662.19**
TOTAL										**$76,967.19**

Table 5 - Antenna foundation costs, detailed.

Antenna Location	Antennas	Subtotals
Local Antenna	168	$12,930,487.73
Remote Antenna	46	$3,540,490.69
VLBI Sites	30	$2,309,015.67
SBA Antenna*	19	$731,188.29
Total Cost	**263**	**$19,511,182.38**

Table 6 - Antenna foundation costs, summarized.

In summary, each antenna foundation is estimated at $76,967.19. Antenna foundations for all 263 antennas will cost $19,511,182.38. (* 6m SBA antenna foundations were estimated at half the price of the 18m antennas.)

9.2.2 Antenna Security Fences

Many ngVLA antennas will be located in areas also used for grazing. These antennas require protection, such as a perimeter fence, from any damage that could be caused by cattle and other wild beasts. Like the JVLA, it is assumed the closest-in antennas for the ngVLA will be situated on federally controlled property. This section will require a barbed wire fence to delineate it from the local ranches, and to keep cattle away. Four-tier barbed wire fencing installed to surround a one square mile perimeter comes with a cost estimate of $38K.

Of the remaining antennas away from the core (the mid-baseline stations and those installed beyond the federal boundary) protection from animals and security in general must be provided. An estimated cost of $2,000 for chain-link fencing for each of these approximate 100 antennas is recommended, for a total construction cost increment of $200K.

It is assumed the long-baseline stations will be constructed on established sites, which will already provide a suitable level of protection.

The cost estimate for protective fencing around the antennas totals $238K.

9.2.3 Site Geotechnical Surveys

The antenna foundations will be designed based on the geotechnical attributes of the area. For the local antennas, this information is readily available from the days of VLA construction. For the 46 remote antennas, borings and a report are estimated to cost $2,500 per station for a total of $115K.

9.3 Roads

The central core and five spiral arms will require adequate roads during the construction phase and during operations for antenna maintenance. Roads will connect all the antennas in the central core to the support buildings and allow for easy access from one antenna to another for maintenance. The road configuration will require approximately 11.5 miles of access road for the central core alone. Figure 5 details the road concept for the central core from the existing VLA site.

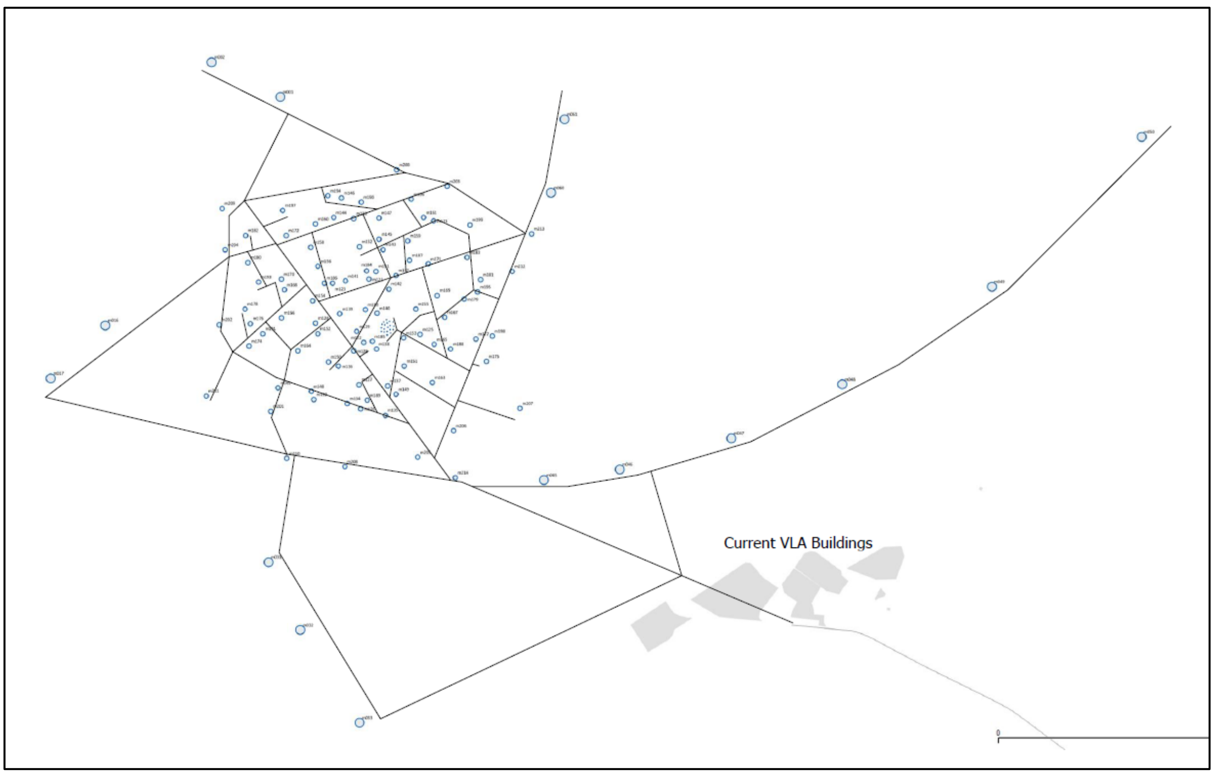

Figure 5 - Road configuration for ngVLA central core and spiral arm antennas.

An access road will follow the five spiral arms and connect all antennas to the central site. Approximately 15 miles of access road will be needed for each of the five arms. In addition to the roads following the spiral arms, a pentagon shortcut located around the 7.5-mile mark on each arm will be added to aid travel from one arm to the next without the need to travel back to the central core. Additionally, an estimated one-mile road extension for remote antennas to be linked to current roads is being used in the estimate. Figure 6 details the spiral arm access roads and pentagon shortcut roads.

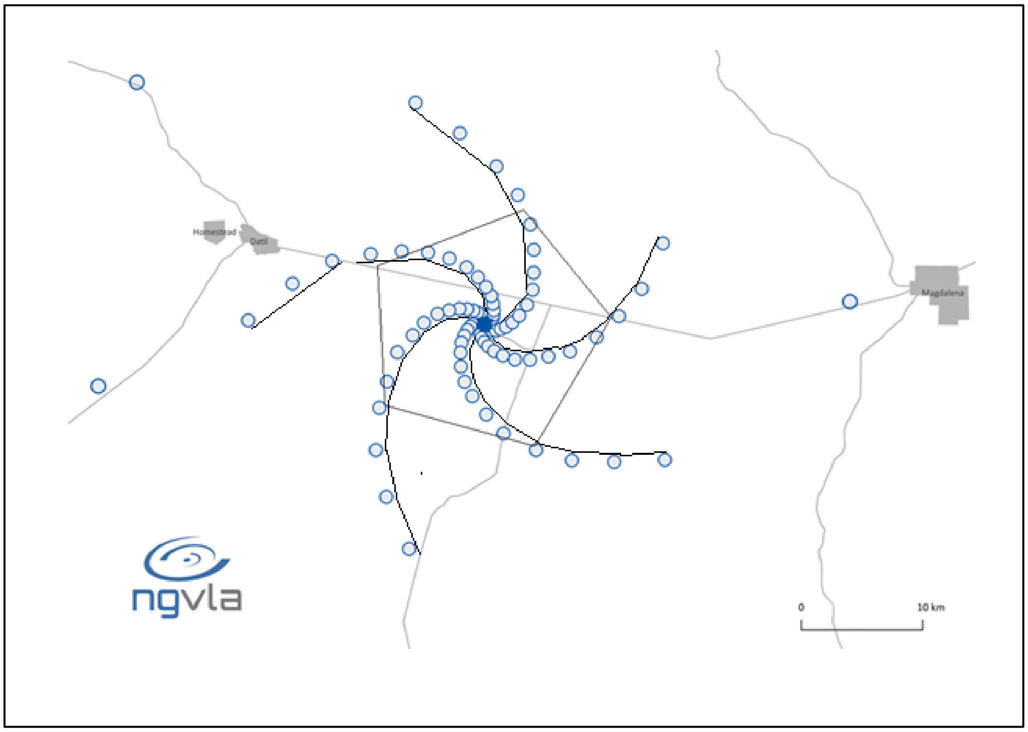

Figure 6 - Road configuration including spiral arm and pentagon short-cut roads.

To assure long life and the ability to facilitate the antenna assembly and maintenance, 6" deep, ¾" crushed stone base will be used on all roads. Furthermore, these improved roads will be more resistant to inclement weather conditions, resulting in considerably less washout, sand migration, and other negative impacts to the surrounding ecosystem.

Table 7 details road costing for the access roads.

ngVLA Road Estimate					
	RSMeans Ref	**Central Core**	**Spiral Arm, Each**	**Pentagon**	**Remote Antennas**
Total Road Required (mi)		11.5	15	32	1
Road Width (ft)		12	12	12	12
Road Area S.Y.		80,960	105,600	225,280	7,040
Crushed 3/4 Stone Base 6", $/S.Y	32 11 23.23 0100	$7.40	$7.40	$7.40	$7.40
Prepare Subbase, $/S.Y	32 11 23.23 8050	$1.20	$1.20	$1.20	$1.20
Subtotal		$696,256.00	$908,160.00	$1,937,408.00	$60,544.00
QTY		1	5	1	48
Total		$696,256.00	$4,540,800.00	$1,937,408.00	$2,906,112.00
Site Total		**$10,080,576.00**			

Table 7 - Cost estimate for ngVLA access roads.

9.4 Buildings

9.4.1 Science and Computing/Array Support Center in Major Metropolitan Area

The following rental rate examples are based on a need for approximately 50,000-70,000 sqft to house the science and array staff. For estimation purposes, a 60,000 sqft building using the $21.17 $/sqft average rate for Dallas is used ($1.27M/yr).

Rental Rate Examples			
Dallas			
Example Location	S.Q.F.T	$/S.Q.F.T Per Year	Yearly Lease
14651 N Dallas Pky	51,283	$15.50	$794,886.50
2401 Cedar Springs	53,012	$36.00	$1,908,432.00
1508 W Mockingbird	65,000	$12.00	$780,000.00
Average		**$21.17**	
Phoenix			
Example Location	S.Q.F.T	$/S.Q.F.T Per Year	Yearly Lease
NW Cooper Rd	60,000	$18.50	$1,110,000.00
3201 E Elwood	76,600	$12.50	$957,500.00
1515 W 14th St	65,000	$19.50	$1,267,500.00
Average		**$16.83**	
Denver			
Example Location	S.Q.F.T	$/S.Q.F.T Per Year	Yearly Lease
3601 Walnut St.	50,801	$34.00	$1,727,234.00
2375 15th St.	69,300	$37.00	$2,564,100.00
2000 S Colorado Blvd	54,700	$30.00	$1,641,000.00
Average		**$33.67**	

The rate table above is for building construction as is and would still require office furniture and support equipment.

9.4.2 New Electronics Repair Facility in Socorro

ngVLA Electronics Repair Center				
	S.Q.F.T	$/S.Q.F.T	RSMeans Ref	Total
Electronics Repair Center	15,000	$271.00	50 17 00 26 0500	$4,065,000.00

The construction cost provided for the Electronics Repair Center does not include laboratory equipment or extra features such as a building Uninterruptible Power Supply (UPS).

9.4.3 Domenici Science Operations Center

Despite the recommendation to relocate science and array support to a city and the electronics support staff to their own facility, the DSOC remains an integral site for observatory support. The DSOC is not optimal to house an electronics repair shop capable of supporting the high volume of ngVLA assemblies and components. With the relocation of a separate electronics repair facility in Socorro, additional DSOC space will become available for overhead departments such as Fiscal, CIS, Purchasing, and HR. $500K is the anticipated cost of any renovation to the DSOC to convert lab space into office space, and to update the infrastructure (power, communications, etc.) of the building.

9.4.4 New Shops, Warehouse, and Offices Near Magdalena

Magdalena Campus Buildings Estimated Costs									
				UNIT COST $/SQFT			COST IN 2018 $		
Building	SQFT	RSMeans Ref	Building Type Comparison	0.25	MEDIAN	0.75	0.25	MEDIAN	0.75
Auto Shop	5,000.00	50 17 00 01 0500	Auto Sales & Repair	165	$173.00	$177.00	$825,000.00	$865,000.00	$885,000.00
Grounds & Facilities	5,000.00	50 17 00 01 0500	Auto Sales & Repair	165	$173.00	$177.00	$825,000.00	$865,000.00	$885,000.00
Machine Shop	8,000.00	50 17 00 26 0500	Eng & Lab Buildings	265	$271.00	$295.00	$2,120,000.00	$2,168,000.00	$2,360,000.00
Warehouse	15,000.00	50 17 00 28 0500		65	$116.00	$226.00	$975,000.00	$1,740,000.00	$3,390,000.00
HVAC & Site Electrical	7,000.00	50 17 00 26 0500	Eng & Lab Buildings	265	$271.00	$295.00	$1,855,000.00	$1,897,000.00	$2,065,000.00
Antenna Technician Work Area	15,000.00	50 17 00 26 0500	Eng & Lab Buildings	265	$271.00	$295.00	$3,975,000.00	$4,065,000.00	$4,425,000.00
Antenna Technician, General R&R									
Cryogenics Technicians									
Servo and Electronics Technicians									
RFI Chamber Building, 900 sqft RFI chamber	2,000.00	See RFI Chamber					237335	237335	$237,335.00
Covered Parking	5,000.00	50 17 00 15 0050		36	$43.50	$47.00	$180,000.00	$217,500.00	$235,000.00
ES&S	2,500.00	50 17 00 01 0500	Auto Sales & Repair	165	$173.00	$177.00	$412,500.00	$432,500.00	$442,500.00
						TOTAL	**$11,404,835.00**	**$12,487,335.00**	**$14,482,335.00**

The warehouse and larger buildings such as the antenna technician work building can be designed from the beginning to serve as integrations centers during construction, and then be modified into operations support centers once construction is complete.

9.4.5 Processor Building at ngVLA Site

This building, which will house the ngVLA Central Processor, will be located in the vicinity of the array core. It will necessarily require a room which is shielded against RFI along with an HVAC system capable of maintaining a safe temperature for the processor. A building-wide or processor-dedicated UPS will also be required.

Locating the building partially underground would increase the RFI protection significantly. An underground processor building has a cost estimate of $3.2M, based on 2018 RSMeans data.

ngVLA Processor Building									
				UNIT COST $/SQFT			COST IN 2018 $		
	SQFT	RSMeans Ref	Building Type Comparison	0.25	MEDIAN	0.75	0.25	MEDIAN	0.75
Processor Building at ngVLA central site	10,000.00	50 17 00 26 0500	Eng & Lab Buildings	265	$271.00	$295.00	$2,650,000.00	$2,710,000.00	$2,950,000.00
with underground construction							$250,000.00	$250,000.00	$250,000.00
						TOTAL	**$2,900,000.00**	**$2,960,000.00**	**$3,200,000.00**

9.4.6 Heavy Equipment Depot at ngVLA Site

A 5,000 square foot covered parking area will be used to house heavy equipment such as cranes and man lifts while not in use. This area will decrease weathering and prolong equipment life.

ngVLA Equipment and Parking depot				
	S.Q.F.T	$/S.Q.F.T	RSMeans Ref	Total
Equipment Depot	5,000	$47.00	50 17 00 15 0500	$235,000.00

The current VLA warehouse and Track/HVAC areas could be repurposed as heavy equipment depots, but given their size they may be better suited for cold storage.

9.4.7 Auto and Heavy Equipment Repair Facility at ngVLA Site

A 5000 square foot auto/heavy equipment repair facility will be needed to perform maintenance and repair to the vehicles needed to maintain the array. The table below details the building costing for such a facility based on RSMeans data.

ngVLA Auto Repair Facility, On Site				
	S.Q.F.T	$/S.Q.F.T	RSMeans Ref	Total
Repair Facility	5,000	$97.00	50 17 00 09 0500	$485,000.00

9.4.8 Remote Support Stations

Remote support stations located strategically to support the most outlying antenna will be capable of housing a staff of 5 technicians and support equipment. The remote support stations are estimated to be approximately 2,700 sqft. Each station will have 1,500 sqft of office and lab area including required facilities. A 1200 sqft high bay shop area will house service vehicles and other required equipment. The table below details costing based on RSMeans data.

ngVLA Remote Support Station				
	S.Q.F.T	**$/S.Q.F.T**	**RSMeans Ref**	**Total**
Remote Support Station	2,700	$97.00	50 17 00 09 0500	$261,900.00

9.4.9 RFI Chamber

The testing and characterization of assemblies and equipment for potential RFI is a constant requirement for a radio astronomy observatory.

RFI Chamber Cost Estimate		**RSMeans Ref**
Building size S.F.	2000	
RFI Chamber size S.F.	900	
W (FT)	30	
L (FT)	30	
H (FT)	10	
Building Unit Cost	$97.00	50 17 00 09 0500
Building Cost	$194,000.00	
Wall and Ceiling S.F.	2100	
Floor S.F	900	
Wall and Ceiling Shielding, 12 OZ panel, Unit price	$12.60	13 49 33.50 0100
Floor Shielding, 12 OZ copper panel, Unit Price	$18.75	13 49 33.50 0150
Total Shielding	$43,335.00	
Total	**$237,335.00**	

9.5 Site Support

9.5.1 Site Water and Sewer, Trash Removal

The aging VLA water and sewer systems were designed to accommodate over 100 employees stationed at the site. While the ngVLA will not have this many people working on the site at one time, a well to provide water for firefighting remains a requirement. The current sewage lagoon is in good shape, but it may require a redesign for smaller capacity. Alternatively, an underground septic system may be the wiser choice.

The cost to re-work or drill a new site well, install pipe to the Processor building, and install a small septic system is estimated to be approximately $250K.

The current method of trash disposal at the JVLA is not sustainable. The on-site landfill which has served as the repository for decades of trash generated at the JVLA is quickly running out of space, with no clear way of expanding the pit. Furthermore, environmental regulations are much stricter than at the time of original construction. Obtaining a permit from the New Mexico Environmental Department (NMED) is not a given. The ngVLA site will produce much less volume of trash than the JVLA. It is the recommendation that in lieu of building a new landfill, a kind of mobile transfer station be employed. At a cost of approximately $250K, a garbage truck with compactor that could be periodically driven to the Socorro landfill would serve this purpose.

9.5.2 Fiber Communications

On the ngVLA site, fiber between the processor building and the array will be direct buried along with the power cables. For remote locations, a similar technique will be used. For estimation purposes, the lengths of the antenna access roads and other roads at the site are used as a basis to estimate fiber length. For remote locations, an average distance of one mile per location is used. No provision is made to estimate the cost of the fiber between the ngVLA site and Socorro, nor is any attempt made here to estimate the cost of rented fiber for the long-baseline stations. The cost estimate for a sufficient length of 24-strand Single Mode Fiber (SMF) to outfit the ngVLA is $900K.

9.5.3 Site Communications

$200K is estimated for site phones and internet installation.

9.5.4 Trash Transfer Station and Recycling

$250K for a compacting garbage truck is estimated.

9.5.5 Weather Station Infrastructure

Weather stations are required at each of the 46 remote mid-baseline and ten long-baseline locations, with another seven situated around the core and spiral arms site. The infrastructure for 63 weather stations, which includes the pad, tower, and hardware has a cost estimate of $656K. This does not include any electronics associated with the weather stations.

ngVLA Weather Station Tower							
	L.F	**C.Y**	**$/L.F.**	**$/C.Y**	**Qty.**	**RSMeans Ref**	**Total**
Center Foundation Pile 2'-6" Diameter, 4' Deep	4		$68.50		1	31 63 26.13 0300	$274.00
Pile Mobilization					1	31 63 26.13 4600	$2,975.00
Guy Wire Anchor Blocks (footings)		1.33		$430.00	3	03 30 53.40 3825	$1,715.70
Guyed Tower, 50' 90 MPH Wind						33 81 13.10 0100	$5,450.00
	Total Per Tower						$10,414.70
	Estimated Towers						63
	Total						**$656,126.10**

The weather stations will also require power and fiber for each location. Trenching planned for antenna power and fiber should be used for the weather station infrastructure, if possible. The approximate cost to purchase armored direct burial fiber ($0.59/ft) and power conductor ($0.80/ft) to each weather station is estimated to be $356K. Infrastructure required to support the ngVLA weather stations has a total cost estimate of $1.012M.

10 Alternative Design and Cost Reduction Options

10.1 Leverage Existing VLA Buildings and Infrastructure

Section 8.1 presents an overview of the findings of the VLA buildings and infrastructure assessment. At the time of this report, a cost estimate to update the site to acceptable standards is not available.

In addition to cost, there are additional concerns with re-purposing the existing structures and utilities to serve the ngVLA mission. Installation of fiber and power to the new array from existing buildings would necessarily cross paths with existing buried lines. Any transition between JVLA and ngVLA that involves having both operational at the same time would have additional and severe complications. Furthermore, the work required to excavate for new lines could easily damage existing ones, rendering the JVLA inoperable until repairs could be made.

10.2 Power Redundancy for Processor Building and Central Site

As specified in this reference study, the Processor Building has but a single power feed. If the switchgear that supplies this feed is down due to failure or maintenance, the array will not be operational. To mitigate this situation, a secondary feeder from an alternate point in the grid could be installed, but whether the cost is justified to implement this is not clear.

Maintenance on the switchgear that feeds the Processor Building is anticipated to take a single day per year. With proper spares on hand, failures such as a defective breaker would require a relatively straight forward maintenance visit from the electricians to replace the defective assembly. Nonetheless, in the event of a massive failure in the switchgear, a redundant unit would be welcome.

Redundancy could be designed in to the electrical infrastructure design to mitigate this type of power failure at an approximate cost of $250K. This would include the additional routing of power cable from the grid to a separate enclosure containing two breakers capable of sustaining power to the Processor Building.

10.3 Potential Cost Reductions

In the event that it becomes necessary to reduce the expense of this project there are several tradeoffs that may be made with only moderate impact to the design and functionality of the proposed system.

10.3.1 Plains Array Switchgear

The proposed arrangement of distribution switchgear divides antennas into 23 groupings. Reducing the number of groupings by 25% yields a corresponding reduction in equipment costs. Based on the quotes received during the EIU at the JVLA, this reduction is estimated as being approximately $300,000.

The tradeoff provided by this cost reduction is primarily a reduction in array performance during maintenance operations. Shrinking the number of antenna groupings necessitates an increase in the number of antennas within those groups, and, consequently, the number of antennas brought offline during maintenance of any line-side components between those antennas and the distribution switchgear.

10.3.2 Generators

Several avenues exist for reducing equipment costs related to generators. In what is likely the simplest method of reducing these costs, it may be possible to reuse the backup generator installed new at the VLA in 2018. This 3MW unit is expected to have few hours of use by the time ngVLA begins construction. As such, it will likely be a prime candidate for generator #2, reducing the $6M estimate down by roughly one-third. There is some risk in reusing the generator instead of purchasing a new one, but, barring the unforeseen, this should be negligible.

Another method to significantly reduce system cost would be to downgrade the proposed generators from prime source ratings to emergency backup rated units. This would cut construction costs for the generators by approximately 10%. Downgrading the units in this fashion would impact EPA permitted runtimes, and warrants further investigation.

10.3.3 Above Ground Processor Building

$250K in savings could be realized should the project decide upon an above-ground processor building.

10.3.4 Eliminate Remote Support Stations

At a future date, should the operations plan no longer require remote support stations, construction costs would be reduced by $1.31M.

11 Options vs. Cost

11.1 Assumed Costs

Assumed Costs			
Electrical Grid, HV Equipment	$60.2M	Water/Sewer (central site only)	$250K
Antenna (Pads and Fences)	$20M	Communications (central site only)	$200K
Fiber (24 SMF cable only)	$900K	Waste Transfer Station (central site)	$250K
Roads	$10.08M	Weather Station Pads, Towers, Fiber, Power (65)	$656K
DSOC lease with renovation	$500K + $280K/year	Visitor Center	$705K
UPS for Machine Shop	$150K	Geotechnical surveys for remote sites	$115K
Total Assumed Costs			**$94M + $280K/yr**

11.2 Building Costs – Options

Building Costs - Options			
1. Renovate existing VLA Buildings and Infrastructure	$20M	6. Central Processing Building – below ground	~$3.2M
2. Science/Computing Support Center lease (metro location)	$1.27M/yr.	7. Heavy Equipment Depot	$235K
3. Magdalena Campus	$14.48M	8. Heavy Equipment Repair Facility	$485K
4. Electronics Repair Facility in Socorro	$4.07M	9. Remote Support Stations (5)	$1.31M
5. Central Processing Building – above ground	$2.95M	10. RFI Chamber for Processor	$237K

11.3 Building Plan Options

The table below provides a snapshot of the key building plan options. Overall, the implemented building scheme does not have a great impact on overall construction cost.

Scheme	Description	Cost	Notes
Assumed Costs & 1	Existing VLA structures, utilities, and other infrastructure will be upgraded to current standards and leveraged to accommodate the ngVLA. Duty stations remain mostly unchanged.	$114M + $280K/yr	Concerns: RFI exposure, Insufficient space for maintenance staff, no extra space for integration during VLA to ngVLA transition and other major transition problems.
Assumed Costs & 3–5, 7, 8–10	Discontinue operations at the current site. Current site buildings could be reutilized for storage. Renovate DSOC for Science, Computing, & Electronics repair. Create Magdalena Campus, remote stations, and above ground site Processor & Heavy Equipment facilities.	$117.8M+ $280K/yr	Concerns: Sufficient space for staff in DSOC, DSOC not well suited for product integration, difficulty in recruiting/retaining scientific and computing staff to Socorro. Reduced, but present RFI concern at site.
Assumed Costs & 2–5, 7, 8-10	Same as above, with relocation of Scientific and Computing staff to a major metropolitan area. Above ground Processor building.	$117.8M + $1.6M/yr	Same as above, with better RFI protection for Processor and more favorable location for Science and Computing recruitment and retention.
Assumed Costs & 3, 4, 6–10	Renovate DSOC for science, computing, and observatory support groups, establish technical repair facility in Socorro, remote stations, and a Magdalena campus. Processor building is under ground. Current site buildings could be reutilized for storage.	$118M + $280K/yr	Concerns: Scientific and Computing staff recruiting and retention, RFI protection for processor could be better.
Assumed Costs & 2–4, 6–10	Same as above, with relocation of Scientific and Computing staff to a major metropolitan area. Underground Processor building.	$118M + $1.6M/yr	Reference Design Recommendation. Above concerns mitigated.

12 Recommendation

The existing JVLA buildings and infrastructure are outdated and in need of an expensive renovation (and likely expansion) to support the project mission of the ngVLA. For some of the infrastructure, complete replacement must take place. Also, any major work done on the existing facilities would have a severe impact on a successful transition between JVLA and ngVLA operations. For these reasons, we believe entirely new structures must be built to support the regular operations and maintenance of the array.

Furthermore, in agreement with the operations concept and due to RFI concerns, it is recommended that only the minimum number of staff be stationed near the core and plains arrays. One way to accomplish this is to create a "Magdalena Campus" for Tier 1 technical staff and other support staff who require close proximity to the antennas. Additional technical staff who require more sophisticated laboratories will be located in Socorro, NM, in a new state-of-the-art facility on or near the campus of New Mexico Tech. The existing DSOC building will continue to be used for other NRAO personnel, such as Fiscal, Purchasing, HR, and CIS.

To improve recruitment and retention of scientific and computing staff, the establishment of a center in or near a major metropolitan area is recommended.

Finally, it is the recommendation of this study to establish five regions for the mid-baseline antennas. The antennas in each region would be serviced by staff working out of a remote support station within the region. These facilities could be located in towns that are centrally located within the region.

13 Appendix

13.1 Abbreviations and Acronyms

ADA	Americans with Disabilities Act
AIV	Antenna Integration and Verification
CNC	Computer Numerical Control
DBE	Digital Back-End
DSOC	Domenici Science Operations Building
DTS	Data Transmission System
EIU	Electrical Infrastructure Upgrade
EMS	Emergency Medical Services
ES&S	Environment, Safety, and Security
HVAC	Heating, Ventilation, and Air Conditioning
kVA	kilo-Volt-Ampere
LV	Low Voltage
LRU	Line Replaceable Unit
M&C	Monitor and Control
MV	Medium Voltage
MVA	Medium-Volt-Ampere
NMT	New Mexico Tech (New Mexico Institute of Mining & Technology)
ngVLA	Next Generation VLA
NRAO	National Radio Astronomy Observatory
SCADA	Supervisory Control and Data Acquisition
SOC	Science Operations Center
UPS	Uninterruptible Power Supply
VLA	Very Large Array
VLBA	Very Large Baseline Array

13.2 VLA Demolition Costs

The table below details the estimated cost to demolish the existing site buildings. These costs are provided for reference only, and are not considered for ngVLA construction.

Building Demolition														
							RSMeans Ref		RSMeans Ref	RSMeans Ref	RSMeans Ref			
							02 41 16.30 0020-0080		02 41 16.17 0420	02 41 16.17 1080	02 41 16.17 4250			
	Occupied	Common	Total S.F	Height	Volume C.F	Volume C.Y	Demolition Cost C.F.	Footing Length L.F	Slab Demo S.F	Footing Demo L.F		Disposal	Demolition Cost	Total Demo Cost
Warehouse	266	4595	4861	15	72915	2700.555556	$0.36	300	$1.09	$14.00	$17.90	$48,339.94	$36,277.74	$84,617.68
Tech Services	1029	7347	8376	15	125640	4653.333333	$0.36	420	$1.09	$14.00	$17.90	$83,294.67	$61,153.22	$144,447.89
Maintenance Building	359	6294	6653	15	99795	3696.111111	$0.36	370	$1.09	$14.00	$17.90	$66,160.39	$49,083.15	$115,243.54
Track+HVAC	N/A	5000	5000	30	150000	5555.555556	$0.36	300	$1.09	$14.00	$17.90	$99,444.44	$64,195.00	$163,639.44
Generator Building	0	2003	2003	20	40060	1483.703704	$0.36	186	$1.09	$14.00	$17.90	$26,558.30	$19,427.20	$45,985.49
Carpenter Shop	119	1271	1390	15	20850	772.2222222	$0.36	154	$1.09	$14.00	$17.90	$13,822.78	$11,328.61	$25,151.39
A.A.B. Building w/ Transporter	1005	21570	22575	115	2596125	96152.77778	$0.36	408	$3.00	$14.00	$17.90	$1,721,134.72	$1,014,814.50	$2,735,949.22
Paint Booth	0	2600	2600	15	39000	1444.444444	$0.36	216	$1.09	$14.00	$17.90	$25,855.56	$20,181.40	$46,036.96
Control Building			22321	30	669630	24801.11111	$0.38	455	$1.09	$14.00	$17.90	$443,939.89	$287,592.28	$731,532.17
Visitors Center			2851	12	34212	1267.111111	$0.38	184	$1.09	$14.00	$17.90	$22,681.29	$18,994.91	$41,676.20
Cafeteria			5175	15	77625	2875	$0.38	312	$1.09	$14.00	$17.90	$51,462.50	$40,070.33	$91,532.83
										TOTAL		**$2,602,694.47**	**$1,623,118.33**	**$4,225,812.80**

The table below details the estimated cost for VLA antenna pad demolition. The cost is to cut the concrete antenna piers flush with ground level and dispose. These costs are provided for reference only, and are not considered for ngVLA construction.

Antenna Pier Demolition	
	CY.
Pier Volume	5.25
Total Volume	1380.75
# of Piers	263
Tons	2796.01875
Loading Charge	$33,138.00
Haul Charge, 50 mi	$8,543.39
Dump Charge	$226,477.52
Pier Cut Cost/Pier	$250.00
Pier Cut cost	$65,750.00
Mobilization 8 weeks	$2,680.00
Crew Subsistence & Lodging	$14,000.00
Total	**$350,588.91**

13.3 VLA Demolition Gains

The VLA rail system contains over 144 miles of 90lb rail. This rail has a high scrap value and there are companies that will come remove the rail and pay for the steel. This means that not only is the rail a zero cost demolition, but we can actually recoup money for the rail. The table below details the scrap value of the rail based on a 50% scrap price. This estimate is provided for reference only, and is not included in this reference design.

Rail Demolition	
Track Length (mi)	36.00
Rail Length (mi)	144.00
Rail Length (Y)	253,440.00
Rail Weight (lb/Y)	90.00
Rail Weight lb	22,809,600.00
Rail weight (TON)	11,404.80
Splice Bar Spacing (Y)	10.00
Splice Bar Weight (lb)	66.00
Splice Bar Weight lb	1,672,704.00
Splice Bar Weight (TON)	836.35
Total Steel Weight (TON)	12,241.15
Scrap Steel Price $/TON	$100.00
Total Scrap Price	**$1,224,115.20**

13.4 Electrical Staffing

The following FTE estimates are for sufficient electrical staffing to maintain the ngVLA. This information is outside the scope of this document and is provided here for reference only. All values are subject to change.

The JVLA currently has an electrical power division consisting of five members. These staff members include one engineer, three electricians, and one technician. This number is expected to grow to approximately eight. Maintenance of the JVLA is estimated as follows:

- Corrective Maintenance
  - Array------------------------- 0.50 man-years
  - Facilities --------------------- 1.25 man-years
- Preventative Maintenance
  - Array------------------------- 0.75 man-years
  - Facilities --------------------- 1.00 man-years
- Engineering---------------------------- 0.75 man-years
- Management -------------------------- 0.25 man-years
- Training-------------------------------- 0.50 man-years

What these numbers fail to show is the efficiency of the time spent. For example, many corrective maintenance tasks around the array require support from Emergency Medical Services (EMS) trained personnel and removal of power from portions of the array. Both of these concerns affect staffing from other departments (where EMS is pulled from) and impacts the ability of other groups to perform their own work. As such, electricians are often stuck waiting on other groups to complete a job prior to beginning their own tasks.

While the ngVLA will increase the number of antennas tenfold, there isn't a corresponding increase in the level of effort required to maintain the array. For all antennas located in the plains array, engineering estimates maintenance workloads to double. As discussed in the previous section, the maintenance schedule for the ngVLA is expected to be much more relaxed. As such, many of the conflicts between groups working on antennas will be avoided by spacing out maintenance tasks.

As discussed in the preceding section, the fixed locations of the ngVLA antennas is expected to remove one of the largest corrective maintenance tasks within the array. Repairing antenna plugs and jacks will no longer be an issue.

The majority of time currently spent on preventative maintenance tasks throughout the array is travel. Neither inspections nor exercising breakers takes much time for an individual antenna, it is more the physical distance between each location that limits the number of inspections that can be performed within a day. The distances involved with the plains array are comparable between the JVLA and the ngVLA, leading Engineering to estimate this as a 50% increase.

Present expectations are for the supporting facilities (offices, labs, and workshops) will require only a slight increase in support, between 0.5 and 1.0 man-years. The rough equivalency is based on the assumption that the number of support facilities will not likely change. Rather it is simply the size of the electrical services involved that will increase.

The largest increase in workload is expected to come from the existence of the remote sites. Simply visiting a remote site is expected to be at least a two-day endeavor: one day travel in each direction, in addition to the work assigned for that trip. Added to that is that at least two electricians will be dispatched for any given assignment. This adds up to an expected 2240 man-hours (56 locations x 2 staff x 20 hours round trip), or slightly more than one man-year, in preventative maintenance travel time alone.

Overall ngVLA electrical staffing is planned as follows:

- Corrective Maintenance
  - Plains Array: 1.00 man-years
  - Remote Sites: 1.00 man-years
  - Facilities: 1.50 man-years
- Preventative Maintenance
  - Plains Array: 1.00 man-years
  - Remote Sites: 1.50 man-years
  - Facilities: 1.50 man-years
- Engineering: 0.75 man-years
- Management: 0.25 man-years
- Training: 0.50 man-years