# A PROPOSED GPS GEODETIC HIGH ACCURACY REFERENCE NETWORK FOR THE STATE OF INDIANA

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## NAVSTAR Global Positioning System

Global Positioning System (GPS) surveying utilizes U.S. Department of Defense (DOD) Navigation System with Time and Ranging (NAVSTAR) satellites to determine the position of points on or near the earth's surface. The primary purpose of the NAVSTAR satellite system is to provide global positioning, navigation, and time determination for U.S. military forces. The DOD allows civilian access to a portion of the information transmitted by the satellites. Surveyors, geodesists and others have taken full advantage of this unique opportunity to develop techniques for a host of GPS based applications including surveying, crustal monitoring, and navigation.

The NAVSTAR satellite constellation presently consists of 26 satellites orbiting the earth at a distance of approximately 20,000 km (12,000 mi) above the earth's surface. Three of these satellites are the original prototype Block I satellites, 9 are operational Block II satellites and 14 are operational Block IIA satellites. The older Block I satellites are being phased out in favor of the newer Block II satellites. Ultimately there will be a total of 24 Block II satellites orbiting the earth in 6 orbital planes, 4 satellites per plane. Only one more Block II satellite is required at this time to completely fill the 6 orbital planes.

The GPS surveying technique is unique in that it is a "one-way" system. Terrestrial electronic distance measuring instruments (EDMIs) utilized by surveyors make use of a reflector to return an electromagnetic signal to the transmitter. These "two-way" systems perform distance measurements using multiple frequencies and phase measurement. GPS satellites constantly transmit electromagnetic signals which may be received by special receivers; there is no provision for returning the signal back to the satellite.

The range between receiver and satellite could be calculated by measuring the travel time of the signal from the satellite to the receiver and multiplying by the signal's velocity (approximately the speed of light). Both satellite and receiver are equipped with highly sophisticated clocks; however, since both clocks cannot be synchronized exactly the range cannot be determined directly. An error in clock synchronization of 1 microsecond ($10^{-6}$ sec) would result in a range error of approximately 300 meters (1000 ft)!

## Positioning with GPS

The one-way GPS system is usable in spite of this apparent difficulty. The clock synchronization error is solved by making numerous observations. High speed computers, least squares adjustment techniques, and mathematical models allow the determination of the range from satellite to receiver with little effort on the part of the surveyor. The simplest form of GPS surveying is to occupy a point with a GPS receiver and determine the geodetic coordinates (latitude, longitude, height) of the point with respect to an ellipsoid which mathematically approximates the earth's mean sea level. This method of absolute positioning can be best illustrated with the simple diagrams shown in Figure 1.

Suppose the position of one satellite is known and the range from one satellite to a receiver is measured. It can be deduced that the receiver must be located somewhere on the surface of a sphere having a radius equal to the range centered on the satellite. This is depicted in Figure 1a. Given two satellites of known position and range measurements from each satellite to a single receiver, we know that the receiver must be located on the circle defined by the intersection of the two "range spheres". This is shown in Figure 1b.

If the ranges from three satellites to a receiver are known we can conclude that the receiver is located at one of the two points formed by the intersection of the range spheres. This situation, shown in Figure 1c, is theoretically sufficient because we generally know the approximate coordinates of the receiver location. This knowledge allows us to eliminate one of the intersections from consideration. However, we must use a minimum of four satellites in order to provide a solution to the clock synchronization (bias) problem mentioned previously. The use of additional satellites usually improves the accuracy of the determined receiver position due to the geometry of the satellite constellation.

The method of range measurement described is known as "pseudoranging". The "pseudo" term is attached because the range isn't measured directly in the two-way sense; the clock bias must be estimated using least squares in order to determine the range. Pseudoranging is accomplished using a code signal which is modulated on a carrier frequency transmitted by the satellite. The range between a satellite and a receiver may also be made by making phase observations using a carrier frequency. Carrier phase measurements allow the determination of more accurate range measurements than code pseudoranging.

Through absolute positioning, the location of a single receiver on or near the earth's surface is determined. GPS allows us to perform this type of positioning, but it doesn't provide surveyors with the level of accuracy often required. Depending on the type of receiver employed, the accuracy (one standard deviation) of the receiver's absolute position may be 5 to 100 meters.

The surveying utility of GPS is realized when carrier phase measurements and the method of relative positioning are used. Differencing techniques are used by considering one (or more) stations fixed, i.e., coordinates known. Three dimensional baseline vectors from the known station to unknown stations are determined by occupying the known and unknown stations simultaneously with GPS receivers during an observation session. The baseline vectors permit the calculation of the positions of the unknown stations with respect to the known station. This application of GPS is similar to trilateration.

The accuracy of the baseline vectors varies from a few millimeters to a few meters depending upon the type of receiver used, the length of the observation session, and the satellite constellation geometry. Typical surveying grade (quality) receivers allow the calculation of baseline vectors to accuracies of approximately 5 to 10 ppm (0.5 to 1.0 cm/km).

GPS observations may be made in a number of different modes. The static method is performed by keeping all receivers at the same location for the duration of the session. The length of a session is usually 30 minutes minimum, longer sessions may be required for increased accuracy. Receivers are typically mounted on a tripod using a standard tribrach and adapter.

The kinematic mode of GPS surveying is a general term which usually implies that one receiver is stationary (the base station) while one or more receivers are on the move (rovers). There are a number of different measuring schemes possible for kinematic surveying. The rover may occupy a point for a few minutes and then move on to another point for a similar observation period. This is known as the "stop and go" or "semikinematic" technique. If the rover occupies the same station more than once during the session the technique may be termed "pseudokinematic" or "intermittent static". "On the fly" kinematic surveying is accomplished when the rover is continuously moving, such as in a car or airplane. The accuracies obtained by kinematic techniques are generally less than those returned by static surveying methods.

GPS surveying techniques are extremely useful in control surveying. Survey grade receivers can be used to measure lines ranging from a few meters to fifty kilometers (30 miles) with great accuracy. Intervisibility between stations is not required although station locations must be relatively free from obstructions. GPS is also weather (lightning excepted!) and daylight independent. When a project requires horizontal control over an extended area, GPS is the tool of choice.

Unfortunately, GPS cannot be used to establish accurate vertical control. The vertical component of GPS surveys is given with respect to the ellipsoid. Elevations (orthometric heights) are determined with respect to equipotential surfaces, mean sea level being the reference equipotential surface also known as the geoid. The geoid and ellipsoid are not coincident, the ellipsoid is a smooth surface while the geoid is a complex, undulating surface. The distance between the geoid and the ellipsoid varies with respect to position. The geoid is approximately 30 meters below the ellipsoid across most of the continental U.S. The geoid is a physical surface comprised of global geopotential effects, regional gravity effects and local terrain effects. The most recent model of the geoid for the United States, GEOID 93, is accurate only to approximately 10 centimeters. This level of accuracy obviously cannot be tolerated in most leveling operations.

Horizontal Control Accuracy Standards

The Federal Geodetic Control Committee (FGCC) has developed standards for horizontal and vertical control surveys. The distance accuracy standards for horizontal control networks established by classical methods (triangulation, traversing) are listed in Table I.

**Table I** Classical Horizontal Control Network Accuracy Standards

| CLASSIFICATION | MINIMUM RELATIVE DISTANCE ACCURACY RATIO | PPM |
|---|---|---|
| First Order | 1:100,000 | 10 ppm |
| Second Order | | |
| Class I | 1: 50,000 | 20 ppm |
| Class II | 1: 20,000 | 50 ppm |
| Third Order | | |
| Class I | 1: 10,000 | 100 ppm |
| Class II | 1: 5,000 | 200 ppm |

The FGCC has also developed preliminary standards for horizontal control surveys performed using GPS or other space system techniques. Table II provides a listing of these accuracy standards. The base error component shown in Table II is that error present in the measuring scheme which is independent of the line length. Tribrach centering errors would be included in this component.

**Table II** GPS Horizontal Control Network Accuracy Standards

| ORDER | BASE ERROR | LINE-LENGTH DEPENDENT ERROR |
|---|---|---|
| AA | 0.3 cm | 1:100,000,000 (0.01 ppm) |
| A | 0.5 cm | 1: 10,000,000 (0.1 ppm) |
| B | 0.8 cm | 1: 1,000,000 (1.0 ppm) |

The accuracy standards reveal that the potential accuracies possible with GPS surveying techniques are several magnitudes of order higher than those possible with classical surveying techniques. This has little effect on the property surveyor but, it is of significant interest to geodetic control surveyors. Extremely high accuracy control surveys may now be performed with a fraction of the effort which was required to perform triangulation.

National Geodetic Reference System

The availability of GPS for performing highly accurate control surveys has rendered the classically surveyed control networks somewhat obsolete. The National Geodetic Reference System (NGRS) consists of approximately 270,000 horizontal geodetic control stations within the U.S. Most of these stations were established using classical surveying techniques.

During the early part of this century the first triangulation networks were extended across the United States. There were approximately 25,000 horizontal control stations in existence in 1927. The U.S. Coast and Geodetic Survey undertook an adjustment of these stations at that time to bring all of the stations to a common datum. The North American Datum of 1927 (NAD 27) was referenced to the Clarke Spheroid of 1866 which is a close approximation of the geoid in North America.

By the 1970's, the number of horizontal control stations in the U.S. exceeded 200,000. Inconsistencies in the coordinates of NAD 27 stations due to a number of factors was deemed a problem so significant that a readjustment of the horizontal control stations on the North American continent was initiated by the National Geodetic Survey (NGS) in 1974. The global reference ellipsoid, Global Reference System of 1980 (GRS 80), was used to create the North American Datum of 1983 (NAD 83). The project was completed in 1986.

While the NAD 83 readjustment seemed like an adequate solution, the advent of space measuring systems (Very Long Baseline Interferometry, Satellite Laser Ranging, TRANSIT/Doppler, and GPS) revealed that the general accuracy of the NGRS first order stations (1:100,000) was inferior to that possible with current technology. While this type of accuracy within the NGRS is adequate for most geodetic applications, local inconsistencies, gaps in coverage and other problems within the network make it less than ideal.

A significant problem with the NGRS lies with monumentation. Lack of adequate funding has led to dissolution of a maintenance program for NGRS monuments, many of which were established in the 1940's. Some of the monuments have been disturbed or destroyed due to construction. Because line of sight between stations was the paramount consideration in station selection, many stations are located at the top of hills and mountains. Also, stations are often located on private land. These qualities often translate into an accessibility problem for everyday use by surveyors.

Perhaps the most conspicuous inadequacy of the existing NGRS stations is their lack of suitability for GPS observations. Line of sight to or from a triangulation station was only required along a few discrete corridors, obstructions around a station which did not inhibit the view of other stations were not a concern. The ideal station for GPS observations is free from obstructions from 0° to 360° in azimuth and from 15° above the horizon to the zenith. The ability to see other network stations is not a consideration. Many NGRS stations fail to meet these requirements for GPS observations.

High Accuracy Reference Networks

A High Accuracy Reference Network (HARN) is a three dimensional geodetic network of stations established using GPS observations. A HARN is usually a state-based network consisting of regularly spaced stations. The spacing between HARN stations is typically 25 to 100 km (16 to 62 mi). Ties are made to selected existing NGRS stations, nearby existing HARN stations (if available), and the global Cooperative International GPS Network (CIGNET). A HARN should also be tied to the International Terrestrial Reference Frame (ITRF).

A HARN is three dimensional in that accurate ellipsoid heights are determined by the network observations and adjustment. Accurate mean sea level elevations or orthometric heights can only be determined for the stations by precise leveling from existing vertical control stations. Typically second or third order leveling procedures are used to determine elevations for some or all of the HARN stations. This additional information allows accurate determination of the geoid at the stations of known elevation.

HARNs are either established, ongoing, or being planned in all but 7 of the conterminous 48 states. Indiana is one of the few states without a HARN "in the works". Figure 2 shows the national status of HARNs. Kentucky is in the process of establishing a 40 km HARN. Observations at the 92 stations within the network should be completed in February 1994. Figure 3 is a diagram of the Kentucky HARN.

Because GPS is used for relative point positioning, one must always start from a point of known coordinates. Should the starting point be an existing NGRS station, one could determine the NAD 83 coordinates of other points with respect to the NGRS station. Generally, however, a minimum of two known horizontal control stations are necessary in order to perform the adjustment of a new network with respect to an existing network.

Suppose two second order (1:50,000) NGRS stations are used to control a GPS network. In all likelihood, the baseline vector connecting the two known stations will have a slightly different length than that determined by inversing using the published station coordinates. The accuracy of the GPS vector will probably be on the order of 1:500,000 if single frequency survey grade receivers are used. By constraining the position of the two second order stations the higher accuracy GPS derived baseline vectors would be distorted to fit into the existing control framework. This distortion is undesirable, effectively corrupting accurate baselines. Ideally, network densification is accomplished within a higher accuracy framework.

A HARN is established minimally to B-order accuracy (8 mm + 1:1,000,000) using dual frequency geodetic grade GPS receivers in order to provide a suitable control network for future GPS (and other) surveys. The stations are chosen such that they are easily accessible and provide no obstructions to GPS observations. The maximum station spacing is 100 km (62 mi) and may be considerably less depending on state involvement.

Future GPS surveys within the HARN require little or no adjustment to observations in order to orient the survey within the HARN. The network provides an ideal framework for Land Information Systems (LIS) and Geographic Information Systems (GIS) since all data may be referenced to a common system. This will minimize "fit" problems between data obtained from different sources. The use of independent project datums will no longer be necessary.

The NGS is presently planning to survey HARNs in the remaining states by 1996. They will use a station spacing of 100 km if there is no state involvement. While a HARN of this station density will cost the states virtually nothing, the long-term implications could be significant. Future needs would likely favor a greater station density which could be attained at relatively low cost by prompt action and involvement by state agencies.

Considerations for HARN Station Selection

Because of the needs dictated by GPS observations and the desire for permanence of the network, station selection must involve the consideration of a number of factors. Some of these factors are discussed below.

Clear Horizon - the station should have a clear horizon from 0° to 360° in azimuth and from 10° to 90° in elevation. The clear horizon requirement includes power transmission lines.

Accessibility - stations should be readily accessible by motor vehicle. Parking should be available within a few tens of meters from the station.

Public Land - the station should be located on land which provides free access to the public. There should be no requirement of contacting private parties in order to gain station access.

Disturbance Free - the station location should be free from potential disturbance by construction or other activities at present or in the future.

Stability and Permanence - the ground where the station is located should be stable and not subject to heaving, sliding or shifting. The station monument should be constructed of materials to provide permanence and durability.

Safety - the station should be located away from traffic or other hazards which may interfere with safe occupation of the station.

Tree Growth - consideration should be given to future tree growth or other activities which would encroach on the clear horizon about the station.

Azimuth Marks - the establishment of a visible azimuth mark at each station ensures that the station may be used in conventional surveying methods. Azimuth marks may be established with single frequency receivers following completion of the HARN observations.

Existing Stations - existing NGRS horizontal and vertical control stations which meet the preceding requirements for HARN stations should be included in the network. The use of vertical control stations is prudent since an accurate elevation for the station is already known.

## HARN Benefits

The benefits of a HARN are many and varied. Some benefits have already been mentioned: the creation of a control network possessing uniformly high accuracy; a framework for future GPS and conventional surveys; and a frame of reference for LIS/GIS data. The HARN will also minimize the amount of time required to locate monuments for control surveys since the monuments will be recent and accurate station descriptions will be readily available. The process of searching for existing NGRS monuments frequently requires considerable time and effort.

Since the coordinates of the HARN stations are expressed in state plane coordinates as well as longitude, latitude and height, its implementation facilitates the use of state plane coordinates. The increased availability of stations of known state plane coordinates leads to an increase in the use of state plane coordinates for property surveys and descriptions. This use of a common datum can prevent lost corners.

A HARN is well suited to providing accurate control for projects extending over large areas. Linear surveys for highways, pipelines, and power transmission lines benefit from readily accessible control on a common datum. The HARN eliminates the need for running the length of an alignment twice in order to prove closure. Additionally, the HARN readily allows the surveyor to account for the earth's curvature in these projects.

The horizontal control for photogrammetric surveys is conveniently extended from the HARN using GPS. Vertical control for small scale photogrammetry may be practical using GPS and HARN stations of known elevation, depending on project accuracy requirements. The proposed use of on-board GPS to determine the position of the aerial camera at the instant of exposure will be assisted with the readily accessible control provided by the HARN.

A HARN also assists geodesists in monitoring long term motions of the earth's crust. This is especially valuable in active seismic areas. Since the location of every HARN station is known with respect to every other HARN station in the U.S. and other stations in the world, deformations and shifts in continental plates may also be studied.

The HARN also provides a method of studying the geoid-ellipsoid relationship providing that accurate station elevations are known. Knowledge of this relationship and further densification of the network allows the surveyor to perform GPS "leveling" with increasing accuracy. Over time and with continuing surveys, this leveling technique may rival costly differential leveling.

## The Indiana High Accuracy Reference Network

The NGS is planning to survey a 100 km spaced HARN in Indiana during 1995 or 1996. Since this date is rapidly approaching it is important that the state become involved in the HARN planning process in order to ensure that the project meets the future needs of Indiana - for both the public and private sectors.

Typically a cooperative agreement is reached between the NGS and a state department of transportation to increase the station density for a HARN. The state agency generally provides manpower to do reconnaissance, construct monuments, operate receivers during observation sessions and other tasks in exchange for the NGS to perform the network design, data analysis, and network adjustment. The result is often a network with a station spacing of 30 to 50 km (19 to 31 mi).

Figure 4 shows the location of the existing first order (1:100,000) control in the State of Indiana. Notice the areas in the state which have no first order control stations. Figure 5 is an approximation of a 100 km (62 mi) spacing HARN for Indiana. The state is afforded full coverage by this scheme consisting of 15 stations; however, this station spacing requires approximately 75 to 90 minutes of travel time between stations. Figure 6 is an approximate 40 km HARN for Indiana. This network also provides complete coverage for the state, a total of 93 stations, but with a travel time of only 30 to 40 minutes between stations.

Station spacing of 50 km or less is also critical to obtaining accurate results using single frequency survey grade GPS receivers. Baseline lengths exceeding 50 km cannot be accurately measured using single frequency receivers, due primarily to effects of theionosphere on the GPS signal. Dual frequency GPS receivers can overcome this constraint but at a cost approximately three times that of single frequency receivers.

The station "Bloomington" must be included in the Indiana HARN. This station is a part of the CIGNET and ITRF networks. Its position has been determined using Very Long Baseline Interferometry (VLBI) making it suitable for very precise GPS observations.

The Indiana Department of Transportation (INDOT) has shown some interest in becoming involved with the Indiana HARN. INDOT has not, however, been in contact with the NGS for the purpose of initiating a cooperative agreement to perform the work. INDOT has been in contact with the Indiana County Surveyors Association regarding development of the Indiana HARN. It is logical that INDOT take the lead in the Indiana HARN development process. The NGS is willing to discuss the project with virtually any agency or group showing interest.

Endorsement and involvement by surveyors' organizations such as the Indiana Society of Professional Land Surveyors (ISPLS) and the Indiana County Surveyors Association would be a catalyst to increased state involvement in the project. By offering to donate time to the project and contacting persons at the state level, particularly within INDOT, these organizations may make a 40 km HARN possible. All surveyors will be able to benefit in the future if action is taken soon.

Involvement by an organization such as ISPLS could involve reconnaissance of potential station locations. This should also be of interest to county surveyors since a 40 km HARN would have a station in nearly all counties. These groups could also assist in the construction of monuments and references, making measurements to references, and drafting reference diagrams for each station.

The HARN commitment by INDOT or other agencies should be to provide coordination for the project, provide personnel and/or equipment for the observation sessions, assist in station selection, and perform precise leveling surveys to bring elevations to some or all of the HARN stations. Ideally a state position of Geodetic Advisor could be established. This position, within INDOT, the Department of Natural Resources, or other agency, would serve to oversee the Indiana HARN, serve as a liaison with the NGS, and serve as a geodetic records keeper for the state. Persons needing station descriptions or other geodetic data would be able to contact the Geodetic Advisor for assistance.

The establishment of a GPS Users Group may also be a possibility. A similar group in Oregon was responsible for the development of the Oregon HARN. A users group would bring together those persons and organizations using GPS within the state of Indiana. These persons would obviously have a keen interest in the Indiana HARN. Such a group could also promote the archival of station descriptions and references for GPS stations throughout the state.

## Conclusions

The establishment of an Indiana HARN having a station spacing of approximately 40 km would provide an accurate geodetic reference for the future of the state. The HARN will be a valuable asset for the future. The success of implementing a 40 km HARN is dependent on involvement by the State of Indiana. This involvement may not be possible without endorsement and involvement by surveyors' organizations.

The present value of GPS and a HARN may seem minimal to many land surveyors. Acceptance of the status quo and apathy toward newer technologies such as GPS and GIS may not be alarming to present day professionals. However, surveyors must vigorously embrace the potential for expanding their roles and the definition of the profession. Who better than the surveyor to develop expertise in technologies related to measurements and mapping?

There will always be a need for boundary surveyors but the future also demands that surveyors have the answers for a public blessed with technology but cursed with coordinate systems. Failure to meet the future needs of the public will force the public to search elsewhere for answers. Other professions will readily accept the role most logically filled by the surveyor. This scenario would leave surveyors lamenting their shrinking numbers, work and compensation. Can surveyors afford **not** to keep abreast of technology in a changing world?

## Acknowledgement

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# REFERENCES

Doyle, David R., 1992, High Accuracy Reference Networks; Development, Adjustment and Coordinate Transformation.

Ethridge, Max M., 1989, Does the National Geodetic Reference System Need to be Upgraded? P.O.B. Magazine, Vol. 15, No. 1.

Federal Geodetic Control Committee, 1989, Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, draft version 5.0, reprinted with corrections August 1, 1989.

Federal Geodetic Control Committee, 1984, Standards and Specifications for Geodetic Control Networks.

Hartzheim, Paul J., 1988, A Proposed Wisconsin Geodetic Reference System Surveyed with Global Positioning System Technology. Presented at the ASCE Specialty Conference on Surveying Engineering '89: Managing New Technologies, Denver, CO May 18-20, 1989.

Love, John D., 1993, Extending the High Accuracy Reference Network (HARN) through West Virginia and Kentucky. Presented at the Bi-State Land Surveyors Conference, Huntington, WV, April 14-17.

Love, John D., Hall, L.W., Frakes, S.J., and Zurfluh, R., 1993, Extending the High Accuracy Reference Network (HARN) through Louisiana. Proceedings of the ACSM/ASPRS Annual Convention and Exposition, New Orleans, LA, February 15-18.

Love, John D., and Strange, W.E., 1991, High Accuracy Reference Networks; A National Perspective. Presented at the ASCE Specialty Conference - "Transportation Applications of GPS Positioning Strategy", Sacramento, California, September 18-21.

Riggers, Lyle L., 1993, Written and telephone communications, December.

Zeigler, James H., 1989, The Tennessee Geodetic Reference Network (TGRN) - An update. Presented at the 1989 ASPRS-ACSM Fall Convention, Cleveland, OH, September.

# SATELLITE RANGING

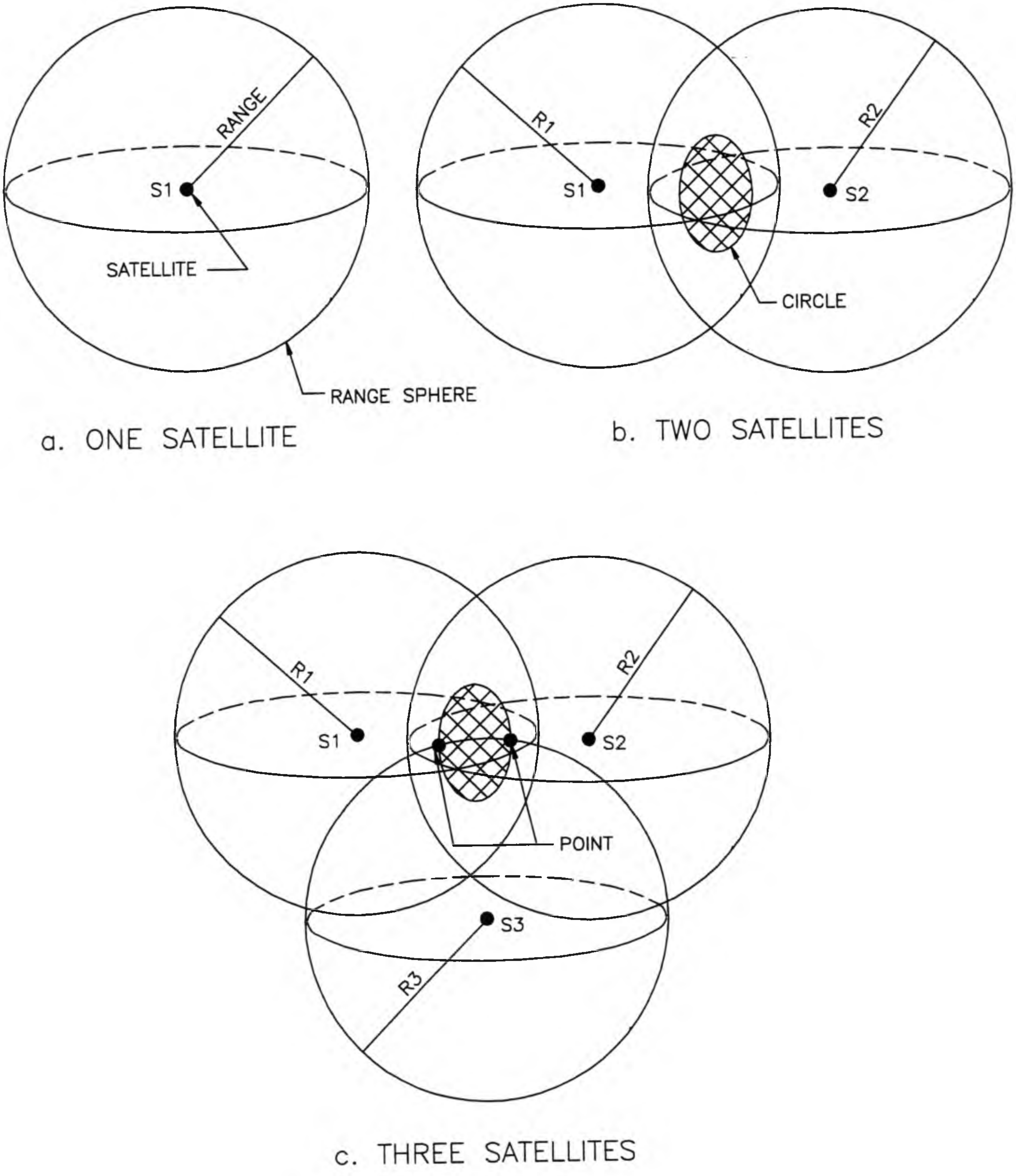
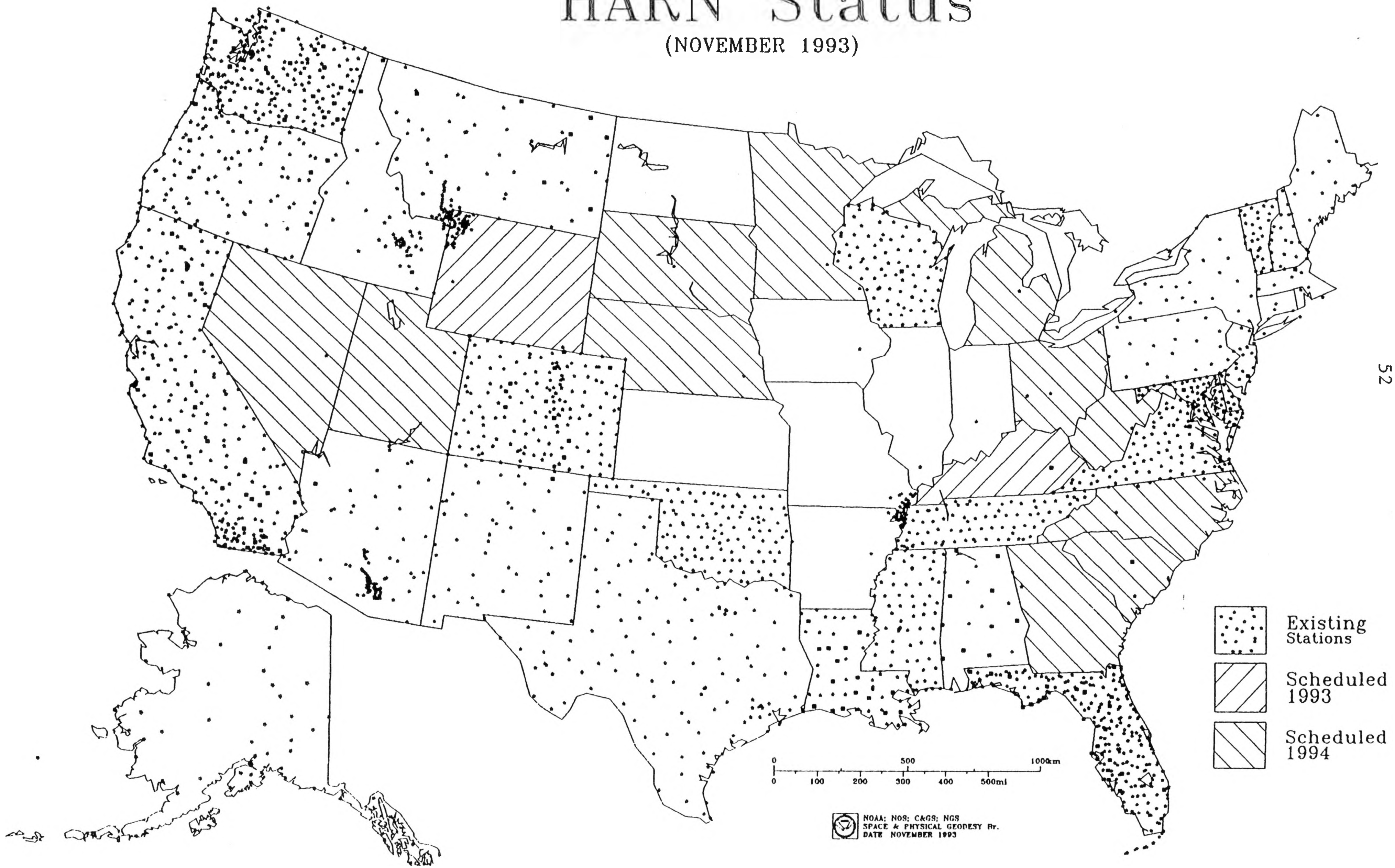
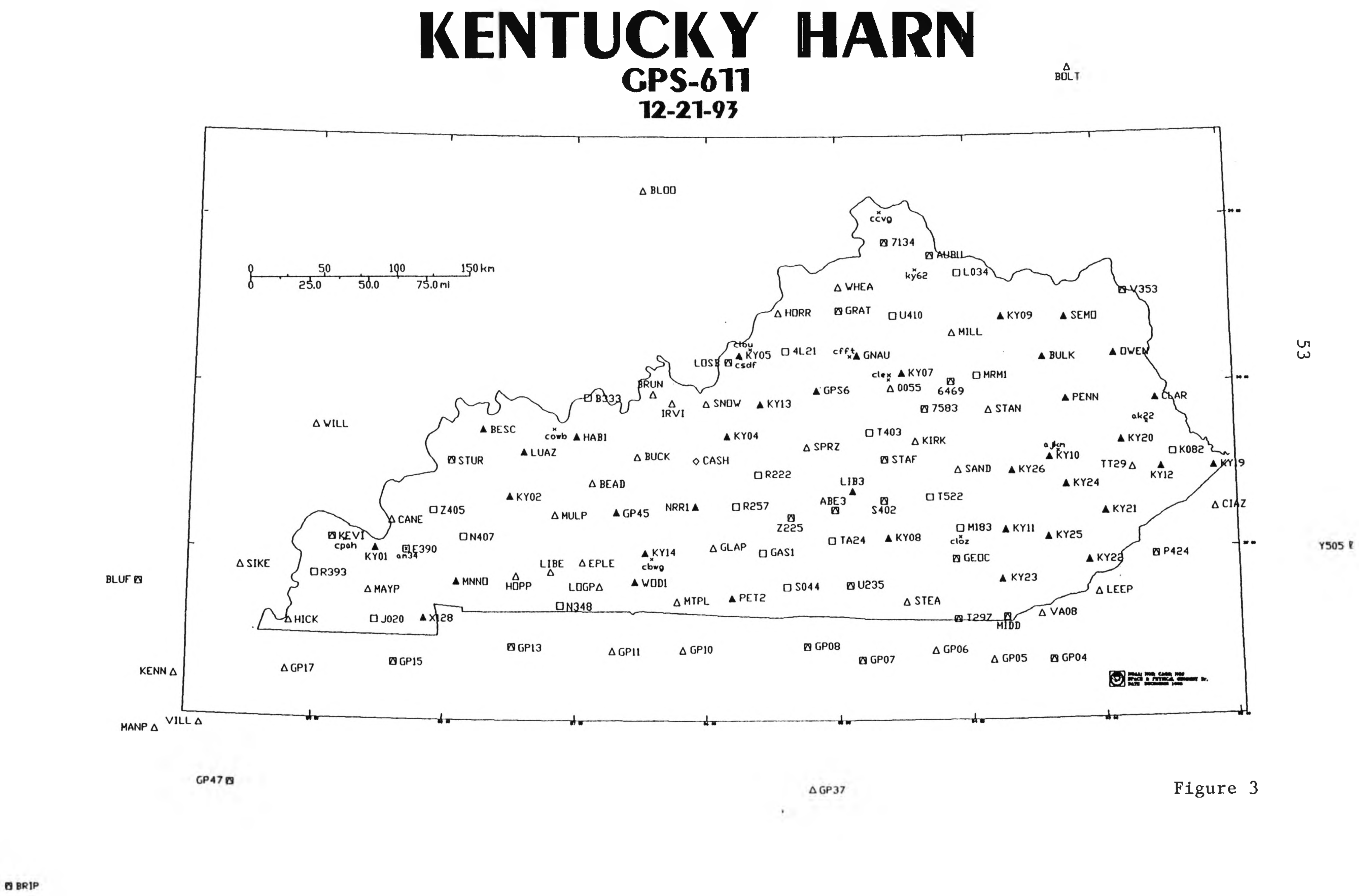



FIGURE 1

# HARN Status

(NOVEMBER 1993)

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HICK
J020
X128
T297
MIDD
VA08
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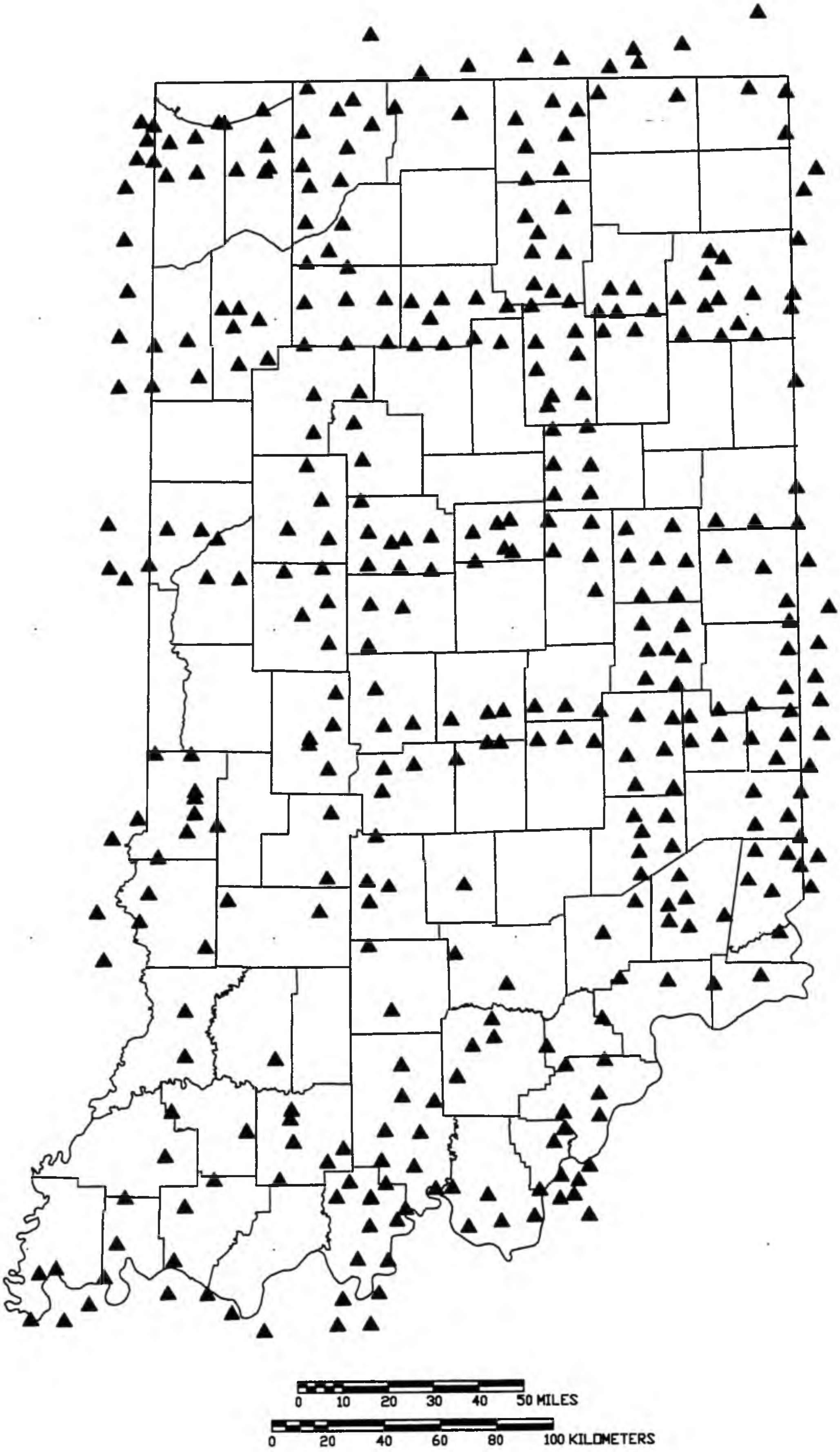
Figure 3

EXISTING FIRST ORDER NGRS TRIANGULATION STATIONS




FIGUR

PROPOSED INDIANA HIGH ACCURACY REFERENCE NETWORK
100 KM STATION SPACING

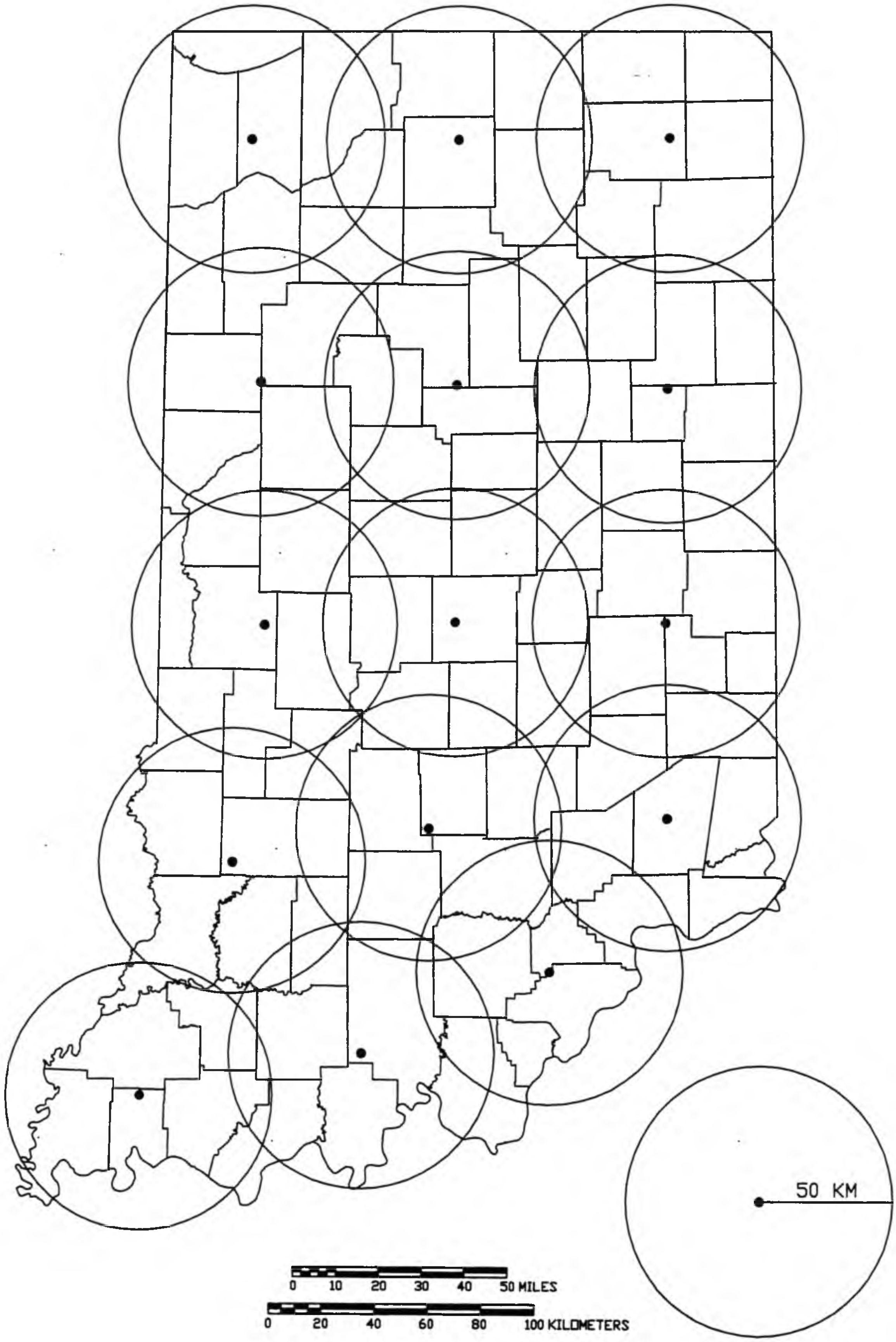
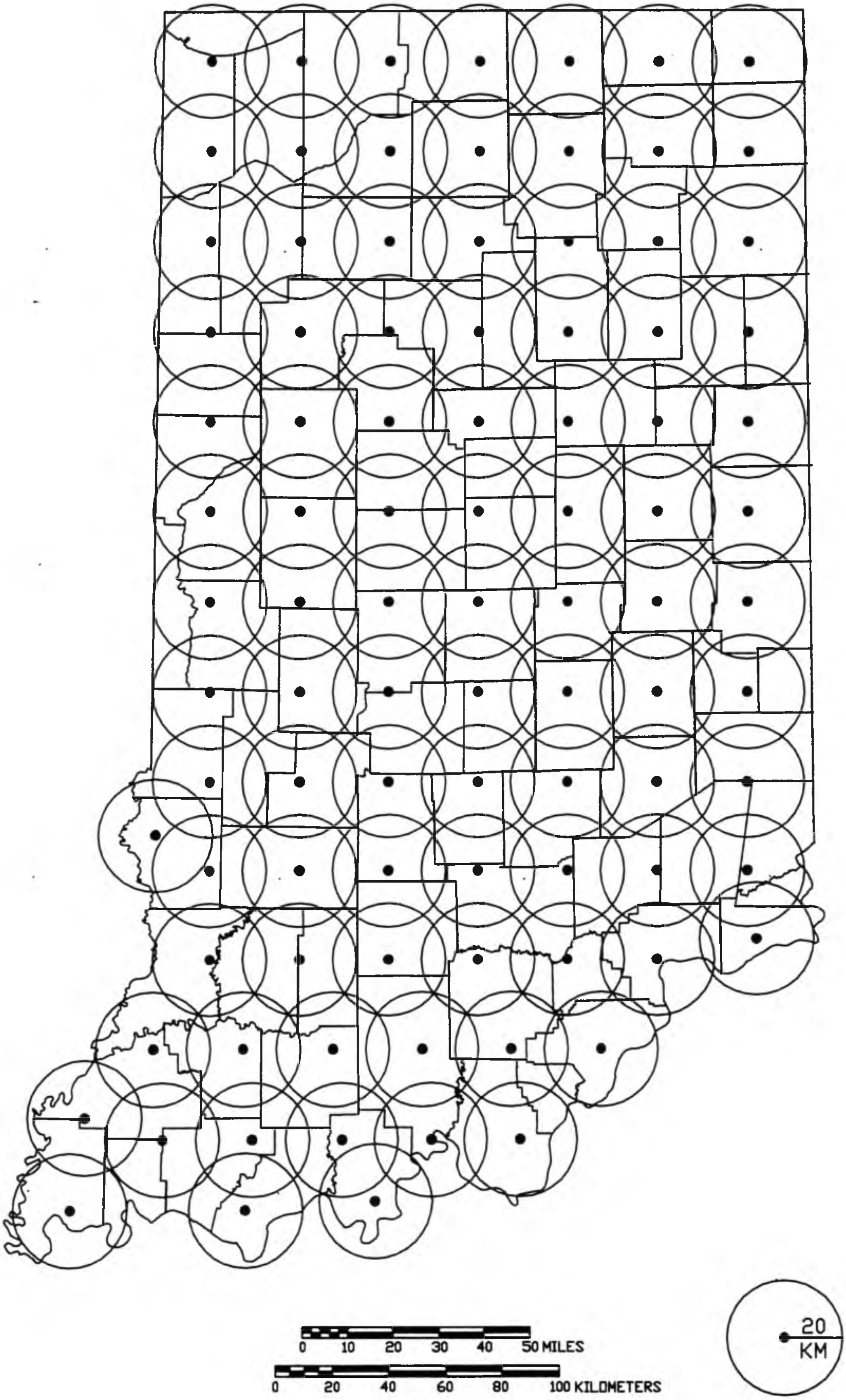



FIGURE 5

# PROPOSED INDIANA HIGH ACCURACY REFERENCE NETWORK
## 40 KM STATION SPACING




FIGURI