

The Magazine of the North American Hydroelectric Industry

Vol. XXV, No. 3, June 2006

HYDRO • REVIEW

Plant Operations:
Reaching Peak Performance

HydroVision
2006
Preview



A New System for Analyzing Precipitation from Storms

To prepare probable maximum precipitation studies, hydro project owners need specific data to develop storm climatology updates, including a comparison of rainfall from recent storms to historic storms that affected the watershed. A new software package provides hourly data that project owners can use to quantify the spatial and temporal distribution of storm rainfall, while decreasing the time and money required for storm analysis.

By Tye W. Parzybok and
Edward M. Tomlinson

To accurately quantify the spatial and temporal distribution of storm rainfall over watersheds, Applied Weather Associates LLC and Metstat Inc. developed Storm Precipitation Analysis System (SPAS). This rainfall analysis software package uses digital precipitation and Geographical Information System (GIS) data to analyze rainfall associated with extreme storms in a GRASS GIS environment.¹ The software provides high-spatial-resolution hourly rainfall fields. These fields then can be used to produce hourly rainfall amounts over user-defined watersheds. The availability of detailed rainfall information allows for runoff model cal-

ibration and verification with improved precision and reliability.² The software lets users retain spatial characteristics of the hourly rainfall fields, or average rainfall amounts over watersheds can be provided. Additionally, the analyzed rainfall fields provide the information required to produce storm depth-area-duration tables. These analyses provide rainfall depths over standardized area sizes and durations.

Hence, extreme storm rainfall can be compared to determine which storms produced the greatest rainfall amounts over various area sizes and durations. Rainfall associated with recent storms can be compared directly with historic storms that occurred over the same climate region. These analyses are required for storm climatology updates used in site-specific probable maximum precipitation (PMP) studies.

Until the 1950s, the Weather Bureau — now called the National Weather Service (NWS) — and the U.S. Army Corps of Engineers routinely performed detailed storm rainfall analyses. Since the 1950s, only a few select storms have been analyzed. SPAS applies the same basic approach as the Weather Bureau and Corps took, thereby achieving a level of consistency between the newly analyzed storms and the historic storms previously analyzed. SPAS also applies several enhancements, including a more advanced daily to hourly rainfall algo-

rithm, higher spatial resolution, and more quality control checks to identify erroneous rainfall reports.³ SPAS has been rigorously tested, both with a theoretical storm where the exact rainfall rates and spatial distribution are known and with historic storms. SPAS analyses also have been completed for several relatively recent extreme rainfall storms, including Hurricane Floyd (September 13-17, 1999). (See Figure 1.)

SPAS analysis results for several extreme rainfall storms have been incorporated into updated technology applications for PMP and probable maximum flood (PMF) analyses.² One example is a site-specific study performed for the Great Sacandaga Lake drainage basin in New York. The Federal Energy Regulatory Commission (FERC) required that Reliant Energy Corp., then the owner of a dam in the basin, perform the PMP study. (The dam is now owned by Brookfield Asset Management). Reliant Energy used SPAS output for Hurricane Floyd, as well as data from several extreme rainfall storms from Hydrometeorological Report (HMR) 51.⁴ However, depth-area-duration tables for more recent (after 1972) storm events had not been produced. So Reliant Energy used SPAS to analyze two rainfall centers, then incorporated this data into the PMP study. The study results provided reduction of 10 to 50 percent from the generalized HMR 51 PMP values (25 percent for the 1,000-square-mile area size and 72-hour duration that most affected the site-specific study), thereby greatly affecting the costs of dam remediation.⁵

Rainfall studies and SPAS

The Weather Bureau and Corps produced many storm studies for extreme rainfall events that occurred during the first half of the 20th century. NWS hydrometeorologists used the depth-area-duration tables from these studies to compare rainfall events and to determine PMP rainfall amounts in HMRs.

Tye Parzybok is president and chief Storm Precipitation Analysis System (SPAS) meteorologist for Metstat Inc. Ed Tomlinson, PhD, is president and senior meteorologist with Applied Weather Associates LLC. Metstat and Applied Weather Associates developed SPAS.

Peer Reviewed

This article has been evaluated and edited in accordance with reviews conducted by two or more professionals who have relevant expertise. These peer reviewers judge manuscripts for technical accuracy, usefulness, and overall importance within the hydroelectric industry.

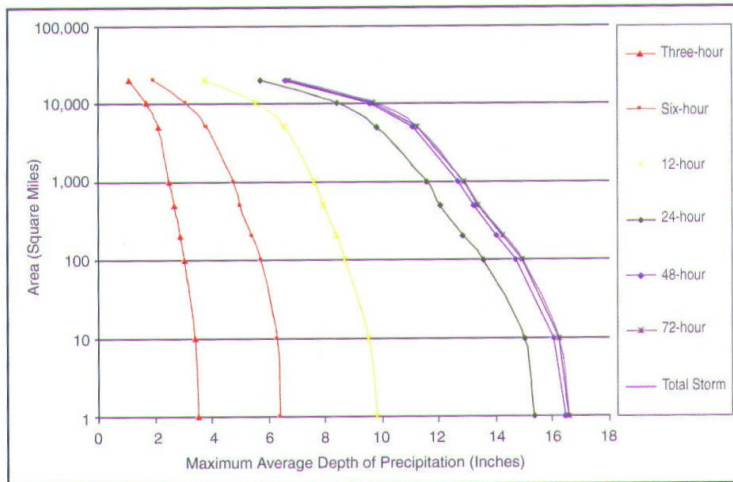


Figure 1: This analysis of total storm precipitation in northeastern Virginia associated with Hurricane Floyd (September 13-17, 1999) was created using Storm Precipitation Analysis System (SPAS). The software package combined several hourly readings to arrive at the total.

Objective procedures were used in these analyses, augmented with subjective judgment by qualified hydrometeorologists.^{6,7} The SPAS analysis incorporates earlier procedures while

providing updated techniques, along with GIS, to improve the quality and speed of the analyses.

With SPAS, storm analyses (including storm-centered depth-area-duration

tables and mass curves) can be completed much quicker and with more detail than historic analyses. In the past, a detailed analysis of a storm's precipitation required extensive manual labor, making it time-consuming and prone to human error. SPAS is largely automated, yet the software provides flexibility and enhancements over the old storm analysis procedure. In the past, it was time- and cost-prohibitive to produce hourly precipitation maps, so assumptions had to be made in the computations of the depth-area-duration results. SPAS requires fewer assumptions because it can better resolve the storm's precipitation through the use of GIS algorithms and hourly precipitation grids. Table 1 compares the procedures used historically by the Weather Bureau and those used by SPAS.

Developing SPAS

One of the most significant strengths of SPAS is its ability to convert daily measured precipitation into hourly precipitation — known as timing — using several nearby hourly stations. In the past, timing of daily measured data was accomplished by associating each daily station with a

Visit us at HydroVision 2006, Booth 644

INTEGRITY ■ INNOVATION ■ PERFORMANCE

**BARNARD
CONSTRUCTION
COMPANY, INC.**

www.barnard-inc.com

CIRCLE 148 ON READER SERVICE CARD

single nearby hourly station and distributing the daily precipitation exactly the same as that hourly station.^{6,7} However, SPAS uses several (user-defined) spatially weighted hourly stations to time each daily station, thereby allowing the hourly precipitation distribution to be unique at each daily station.

The transformation of daily data into hourly precipitation depths is a spatially-based approach that uses the percent of hourly precipitation at the hourly gauges. These percentages are spatially interpolated to a grid. Because the percentages typically have a high degree of spatial autocorrelation, the spatial interpolation carries skill in predicting the percentages at daily-only reporting stations. The end result is a percent grid for each hour of the storm, which the software then uses to create simulated hourly rainfall amounts for daily station rainfall data. Percent values are sequentially extracted from the hourly percent grids and converted into estimated hourly precipitation values for the daily station.

Plots of the incrementally accumulated precipitation data (known as mass curves) are created for each daily station

Table 1: Comparison of Storm Analysis Procedures used by Weather Bureau (Historical) and by SPAS

Topic	Weather Bureau	SPAS
Timing of daily stations	Mimicked hourly distribution of the nearest single hourly station.	Uses nearby hourly stations.
"Pseudo" data	Did not use a systematic procedure for including ancillary information.	Various options to account for complex terrain, unique meteorological conditions, or other ancillary information.
Base map options	No base map, 100-year 24-hour precipitation frequency map, or elevation map.	Multiple, high resolution base map options.
Depth-area-duration calculations	Based on a hand-analyzed total storm, isohyetal map.	Based on high-resolution hourly GIS-created precipitation grids.
Automation	None.	Largely automated.
Reproducibility	Largely not reproducible.	Reproducible.

and then combined into a single plot with other nearby stations for evaluation (see Figure 2). This allows immediate evaluation of the magnitude and temporal characteristics of each station as compared to its neighbors. This is one of several ongoing quality control procedures that take place during the course of the SPAS analysis to ensure the input precipitation data is accurate.

The use of "base maps," which are existing GIS grids of topography or climate or weather variables, assists in defining the spatial variations of the rainfall fields. The spatial patterns of the base maps aid in the interpolation between points of observed precipitation. The use of precipitation estimated by Next Generation Radar (NEXRAD) as a base map has allowed SPAS to bet-

Visit us at HydroVision 2006, Booth 853

Hydropower Licensing Specialists

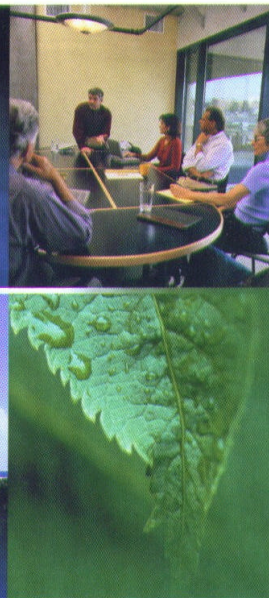
Stephen Padula
PRINCIPAL

LongView Associates, Inc.
2705 NE 163rd Street
Ridgefield, WA 98642
(360) 576-3579
(360) 576-0308 fax

www.longviewassociates.com



CIRCLE 387 ON READER SERVICE CARD



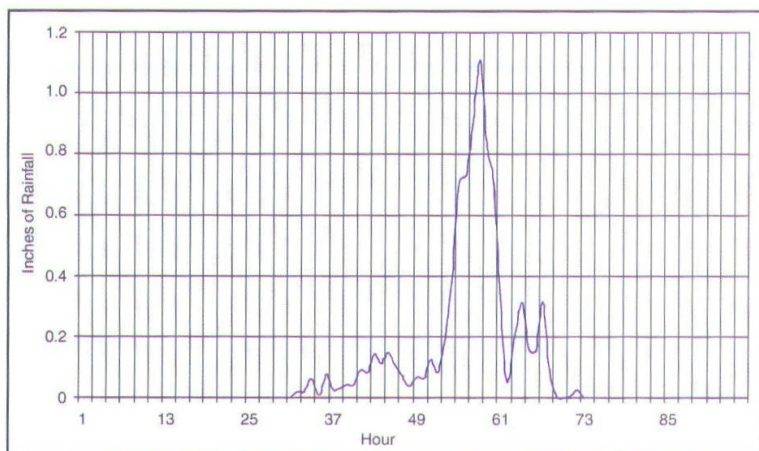


Figure 2: This mass curve, generated by SPAS, shows precipitation at the storm center associated with Hurricane Floyd (September 13-17, 1999) in northeastern Virginia. The curves are created for each daily station, then combined with other nearby stations into a single plot.

ter resolve the relative magnitude and small-scale spatial details of storm precipitation; however, gauge data is the basis for the actual precipitation depths. SPAS base map options include:

- Elevation, Digital Elevation Model (DEM);

- Mean monthly precipitation, Parameter-elevation Regressions on Independent Slopes Model (PRISM);⁸

- Precipitation frequency grids, e.g. NOAA Atlas 14⁹ or TP-40;¹⁰

- Mean annual precipitation, PRISM;⁸

- Total monthly precipitation, PRISM;⁸ and

- NEXRAD estimated precipitation.

Once the hourly precipitation grids are quality controlled and finalized, any subset of hours during the storm can be summed together, displayed, and analyzed. Additionally, any analyzed rainfall field (each hour, summation of several hours, or total storm duration) can be clipped to user-defined watershed boundaries with explicit rainfall amounts over that watershed provided (either spatially distributed or averaged).

Practical uses of SPAS

SPAS quantitatively describes the temporal and spatial characteristics of a precipitation event, thereby providing useful information for a number of practical applications. Although SPAS originally was designed to provide the necessary data to calculate a depth-area-duration table, it has been used in runoff model calibration and validation studies.

Runoff model calibration and validation

Researchers involved in a study for

Visit us at HydroVision 2006, Booth 430

TUFFBOOM®

Log & Debris Booms / Boat Barriers

Worthington Products, Inc.

Tel: 330-452-7400 (USA)

www.tuffboom.com

CIRCLE 305 ON READER SERVICE CARD

Chippewa Flambeau Improvement Co. in Wisconsin used SPAS for runoff model calibration and validation for the Rest Lake and Turtle-Flambeau dams.³ Both dams are located upstream from hydropower projects. After completing a storm search using station data to identify the most extreme historic rainfall events over the basin, stream gauge data availability was evaluated to identify the most appropriate storms for use in model calibration and validation. Hourly rainfall analyses were completed, explicitly providing amounts within the basin boundaries for each hour during the storm period for calibration. For example, the detailed high-spatial-resolution hourly precipitation allowed for accurate determination of the volume of rainfall that fell directly over open water, as well as the hourly volume of rainfall that fell over regions with varying soil types, infiltration rates, and lag times. The high spatial- and temporal-resolution output from SPAS allowed an accurate assessment of historic storm runoff and established a better understanding of how high-runoff events behave and develop.

For this study, the detailed rainfall

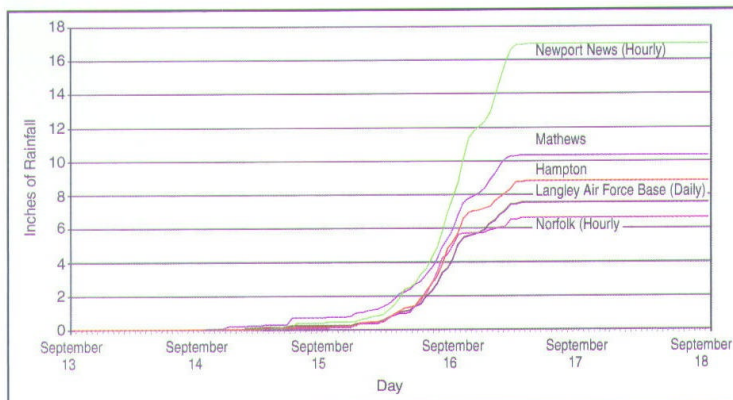


Figure 3: This storm-centered depth-area-duration graph, generated by SPAS, shows the rainfall associated with Hurricane Floyd (September 13-17, 1999) in northeastern Virginia. Hourly precipitation grids serve as the basis for computation of the depth-area-duration statistics.

information allowed modelers to determine that rainfall directly over open water provided almost all of the runoff from the watershed. This level of calibration and runoff evaluation was made possible using the SPAS rainfall analyses results together with GIS analysis of the watershed characteristics to better

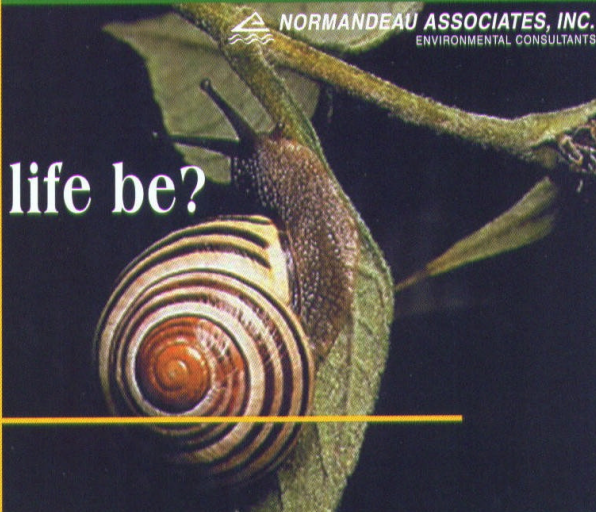
define the topography of the watershed. The use of SPAS allowed once-difficult hydrologic techniques to be solved with ease, accuracy, and efficiency. Users say SPAS "simply solved practical problems that had dogged the analysis of the watershed for years — indeterminate topography and lack of rainfall data —

Visit us at HydroVision 2006, Booth 634

How much easier can life be?

Normandeau Associates offers specialized ecological services to the power industry. Our experts have the experience to deliver economic solutions to the complex strategic environmental, fisheries, and water quality issues of today. We understand the regulatory requirements, are recognized leaders in fish behavior and fish/bypass evaluation, are FERC approved to prepare third party EISs, as well as having relicensing capabilities.

No matter your environmental needs, Normandeau can simplify your life.



NORMANDEAU ASSOCIATES, INC.
ENVIRONMENTAL CONSULTANTS

www.normandeau.com

Bedford, NH
603.472.5191

Drumore, PA
717.548.2121

Stevenson, WA
509.427.4793

Westmoreland, NH
603.355.2333

CIRCLE 243 ON READER SERVICE CARD

Table 2: Storm-Centered Depth-Area-Duration Table for Rainfall in Northeast Virginia from Hurricane Floyd (September 13-17, 1999)

Area (Square Miles)	Duration of Rainfall (Hours)					
	3	6	12	24	48	72
1	3.5	6.4	9.8	15.3	16.4	16.6
10	3.4	6.3	9.5	15.0	16.0	16.2
100	3.0	5.7	8.7	13.6	14.7	14.9
200	2.9	5.4	8.4	12.8	14.0	14.2
500	2.7	5.0	7.9	12.0	13.2	13.4
1,000	2.5	4.8	7.6	11.6	12.7	12.9
5,000	2.1	3.8	6.5	9.8	11.1	11.2
10,000	1.7	3.1	5.6	8.4	9.6	9.7
20,000	1.1	2.0	3.7	5.7	6.6	6.7

adding value to an otherwise conventional PMF analysis.¹²

Analyzing storm depth, area, duration

Storm depth-area-duration analyses are the best means for comparing the magnitude of extreme rainfall storms. (See Figure 3 and Table 2.) The hourly precipitation grids generated by SPAS serve as the basis for the computation of depth-area-duration statistics in SPAS. The SPAS depth-area-duration functionality has been rigorously tested both with a theoretical storm where the exact rainfall rates and spatial distributions are known

and with historic storms analyzed by the Weather Bureau. The depth-area-duration process, by nature, is computationally intensive, hence forcing time-saving assumptions in storm studies conducted by the Weather Bureau, as shown in Table 1. SPAS, however, uses today's computer power and GIS algorithms to compute precise and perhaps more accurate depth-area-duration analyses.

SPAS uses the same general method for determining the storm-centered depth-area statistics as the World Meteorological Organization's *Manual for Depth-Area-Duration Analysis of Storm*

Precipitation.⁶ However, SPAS does not make the assumption that the hourly storm precipitation pattern is constant as dictated by a manually analyzed total storm isohyetal map. Rather, it changes from hour to hour throughout the storm.

In real storm cases, the SPAS depth-area-duration tables results were generally within +/-5 percent of the published Weather Bureau results for the Westfield, Mass., storm of 1955 and Ritter, Iowa, storm of 1953.^{11,12} These results confirm the reproducibility of not only the storm-centered depth-area-duration results, but also the spatial and temporal characteristics of the storm precipitation.

Future SPAS development

SPAS is optimized to be a post-storm analysis tool. However, there is interest in developing a near-real-time or real-time version. Such a version would provide hydrologic engineers and decision makers important detailed information about real-time rainfall events.

SPAS provides a tool for analyzing storm rainfall patterns with improved spatial and temporal resolution that can be used in runoff model calibration and validation. The improved spatial data enables variations in soils types, infiltration rates, and lag times to be associated with detailed rainfall rain rates and volumes. Additionally, the hourly rainfall analyses allow for improvement in runoff timing.

There is a large backlog of extreme rainfall storm analyses that should be completed. With rare exception, extreme rainfall storms that have occurred in the past 50 years have not been analyzed. Without storm depth-area-duration tables, comparison of rainfall amounts from extreme rainfall storms for various area sizes and durations is not possible. The storm databases in most of the current HMRs are significantly out of date (the most recent storm used in HMR 51 occurred in 1972).⁴

Using SPAS, this backlog in storm analyses can be addressed. Equally important, storm analyses could be provided in near-real-time, using rainfall observations that are not included in official archives and providing emergency managers with some measure of how extreme the storm rainfall amounts over various area sizes and for various durations are when compared to other storms, published return frequency values, and published PMP values. ■

Mr. Parzybok may be reached at Metstat Inc., 4764 Shavano Drive, Windsor, CO



- Public Safety
- Debris Control
- Security & Demarcation



Logs and debris
a problem?
Not for our
customers!

Armorfloat barriers provide real debris control solutions.

- Log Boom Systems
- Submerged Screens
- Debris Diversion Panels

Good Innovation, LLC
Sacramento, California, USA
Phone: 916-920-8620 – Fax: 916-920-8618
Email: armorfloat@goodinnovation.com

www.armorfloat.com

CIRCLE 431 ON READER SERVICE CARD

80550; (1) 970-686-1253; E-mail: tyep@metstat.com. Mr. Tomlinson may be reached at Applied Weather Associates, P.O. Box 680, Monument, CO 80132; (1) 719-488-9117; E-mail: awai@adelphia.net.

Notes

¹Geographic Resources Analysis Support System (GRASS), GRASS Development Team, Trento, Italy, 2004, <http://grass.itc.it>.

²Rudolph, Richard M., Ellen Faulkner, Terry Hampton, and Edward Tomlinson, "Old Problems and New Technologies: Spatial Analysis Adds Value to Dam Safety Studies," *Proceedings of Dam Safety '04*, Technical Session I, Association of State Dam Safety Officials, Lexington, Ky., 2004.

³Tomlinson, Edward, and Tye Parzybok, "Storm Precipitation Analysis System (SPAS)," *Proceedings of Dam Safety '04*, Technical Session II, Association of State Dam Safety Officials, Lexington, Ky., 2004.

⁴Schreiner, Louis C., and John T. Riedel, *Hydrometeorological Report No. 51 Probable Maximum Precipitation Estimates, United States East of the 105th Meridian*, Hydrometeorological Branch Office of Hydrology National Weather Service, Silver Spring, Md., June 1978.

⁵Tomlinson, Edward M., Ross A. Williams, and Tye W. Parzybok, *Site-Specific Probable Maximum Precipitation (PMP) Study for the Great Sacandaga Lake/Stewarts Bridge Drainage Basin*, Prepared for Reliant Energy Corporation, Liverpool, N.Y., September 2003.

⁶*Manual for Depth-Area-Duration Analysis of Storm Precipitation*, World Meteorological Organization, Geneva, Switzerland, 1969.

⁷Shands, A.L., and G.N. Brancato, *Applied Meteorology: Mass Curves of Rainfall*, Hydrometeorological Section, Office of Hydrologic Director, Weather Bureau, U.S. Department of Commerce, March 1946.

⁸Daly, C., G. Taylor, and W. Gibson, "The PRISM Approach to Mapping Precipitation and Temperature," *Proceedings of the 10th Conference on Applied Climatology*, American Meteorological Society, Boston, Mass., 1997, pages 10-12.

⁹Bonnin, G.M., et al, *Precipitation-Frequency Atlas of the United States*, NOAA Atlas 14, Volumes 1 and 2, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Md., 2004.

¹⁰Hershfield, D.M., *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years*, Technical Paper No. 40, U.S. Weather Bureau, Washington, D.C., 1961.

¹¹*Storm Studies — Pertinent Data Sheet for the 7 June 1953 Storm*, MR 10-8 (HMB 20), U.S. Army Corps of Engineers, 1953.

¹²*Storm Studies — Pertinent Data Sheet for the 17-20 August 1955 Storm*, NA 2-22A, U.S. Army Corps of Engineers, 1955.

Hydro Turbine & Generator Consultants

Troubleshooting

Inspections

Studies

O&M Enhancement

Engineering

Project Management

Installation

Specifications

Alignment

Training

Major Overhauls

Upgrades

Acquisitions



Wenkus Energy, Inc.

... helping you generate your most efficient future

4881 Macks Road
Stewartstown, PA 17363

TEL 717-993-5726

FAX 717-993-5877

EMAIL mwenenergy@blazenet.net

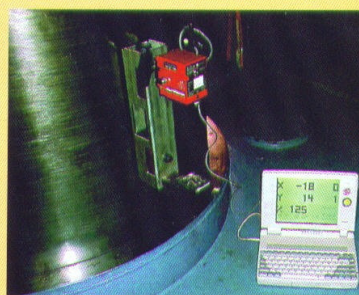
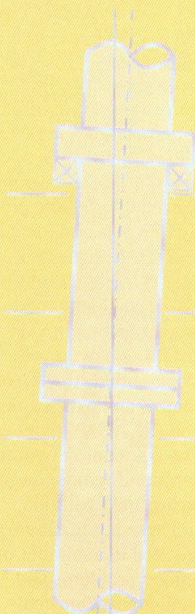
www.wenkusenergy.com

Experience, Diversity & Resourcefulness

CIRCLE 493 ON READER SERVICE CARD

Visit us at HydroVision 2006, Booth 835

Laser measuring of vertical shaft plumbness



PERMAPLUMB® replaces the time-consuming wire method. A self-adjusting mirror—always parallel to the horizon—reflects a laser beam into a vertically mounted transducer which attaches magnetically to the hydro turbine shaft. From a single 270 degree shaft rotation the system calculates and displays angularity and corrective moves. A 'MOVE' function allows monitoring of corrections as they are being made. Adjacent turbines can continue to operate since the system is vibration insensitive.

LUDECA
INC.

(305) 591-8935 • www.ludeca.com
Fax (305) 591-1537 • info@ludeca.com
1425 NW 88th Avenue, Miami, FL 33172

Permaplumb is a registered trademark of Prüftechnik AG.

CIRCLE 277 ON READER SERVICE CARD