The Long-Term Performance of Nevada Geothermal Projects Utilizing Flash Plant Technology

Dick Benoit

Sustainable Solutions

Keywords

Basin and Range power plants, flash plants, case history, Beowawe, Desert Peak, Steamboat Hills, Dixie Valley, Bradys, field management, project performance

ABSTRACT

Five flash type power plants utilizing evaporative cooling have operated on different Nevada geothermal fields for periods of 21 to 28 years with varying degrees of success. The Dixie Valley and Beowawe projects represent long-term successful projects that have operated at capacity factors generally above 85% and have power plants and resources well matched in size. At Beowawe the resource pressures and artesian flow rates have naturally increased to sustain output while temperatures have substantially declined. At Dixie Valley an augmented injection program was needed to stabilize resource pressures and flow rates while the temperatures have suffered modest declines. The Bradys power plant has been the least successful project due to major reservoir cooling. Bradys represents a case of a large liquid volume plant sited on a small resource. The Desert Peak dual flash plant was replaced with a larger binary power plant after operating for 20 years and the project now consists of a medium sized plant on a relatively small resource that has recently been declining in output. The flash plant at Steamboat Hills is one of seven Steamboat plants located on a large reservoir. It is now closely integrated with a binary power plant, and represents a successful case of a small plant located on a large resource.

Introduction

Between 1985 and 1992 flash type power plants commenced operations on the Beowawe, Desert Peak, Dixie Valley, Steamboat, and Bradys geothermal fields. These five projects comprise about 30% of the total currently installed gross geothermal capacity in Nevada. All of these plants were initially installed with evaporative cooling towers that continuously remove significant mass from the reservoir. Since 1986 Nevada geothermal power plant operators have supplied the Nevada Division of Minerals (NDOM) with monthly production and injection statistics of wells in service, sales or net MW outputs, and the nameplate capacities of the power plants. These monthly averaged are usually not supported with any text describing operational events that can result in significant monthly variations. The NDOM numbers have been incorporated into reports by the Nevada Bureau of Mines and Geology (NBMG), the most recent being by Shevenell, et al., (2012). The NDOM and NBMG data and project histories are her used to document the relative success that various operators have had in dealing with changing reservoir parameters over a period of 21 to 28 years.

Multiple nameplates, gross, net, and generating capacity numbers can be found for these projects in public sources and there have been significant changes to the plants over the years. This ambiguity impacts capacity factor calculations making comparisons between the differing projects somewhat arbitrary. Gross and net design values for these projects were researched back to publications at the time of plant construction and these values are utilized, recognizing that they may still not be particularly precise numbers. In geothermal plants the MW outputs are the most precise numbers available to determine the plant performance. Consistently accurate well flow rates are the most difficult values to obtain. Flow rate values reported to NDOM come from variable and at times indirect methodologies over the years. There have been a variety of measurement techniques or assumptions used by the different operators. The individual flow rate numbers need to be viewed with skepticism, even when individual operators have made considerable effort in providing the most accurate numbers. Recent fluid-entry temperature data are not publicly available for the artesian wells supplying these plants. These data would allow for a much improved discussion of the project performances.

Beowawe

The 15.1 MW net (16.66 MW gross) (Table 1) dual flash Beowawe power plant commenced operations in the last week of 1985 with a single Mitsubishi turbine (Mitsubishi, undated) to take advantage of an expiring tax credit. It was jointly developed by the Beowawe Geothermal Power Company, a partnership between

Chevron and a subsidiary of Southern California Edison Company (Elliott, 1986). Chevron performed field exploration activities between 1973 and 1985 in developing the 410 ºF resource with two closely-spaced artesian production wells, and one injector, which disposed of fluid outside of the geothermal reservoir, and a 4 cell wet cooling tower.

The power was originally sold to Southern California Edison at the long-term avoided cost available under a Standard Offer 4 contract with any excess being sold to Sierra Pacific Power Company. Since 2005 the power has been purchased by NV Energy, the successor to Sierra Pacific Power Company. Chevron sold its interest in the project to Oxbow in late 1990. Oxbow managed the project under the name Beowawe Power, LLC and in 2000 sold its interest in the project to Caithness. In 2007 Caithness sold its interest to Terra-Gen Power LLC, the current operator.

The most significant changes to the field since startup consist of drilling a third production well with an exceptionally large 16" diameter production casing in 1991 and placing a second injection well in service to return all injectate to the reservoir in 1994. The power plant was not significantly modified until late 2005. In March 2011 a 2 MW net (2.5 MW gross) bottoming cycle TAS/Barber Nichols binary turbine and a second wet cooling tower became operational (Dickey et al., 2011, Land, 2013). This reduced the injection temperature from 205 ºF to 150 – 160 ºF. One unsuccessful step out well was drilled by Caithness in 2005.

The Beowawe project has never achieved a monthly average of its initial net nameplate value of 15.1 MW (Figure 1). Irregular and declining net MW output defined the first five years of operations due to production well scaling before the carbonate scale inhibition systems were developed and an absence of any excess production capacity prior to 1991. With excess production capacity becoming available in 1991 and injectate being returned to the reservoir, the project operated consistently between 11.5 and 13 net MW with a low decline rate until late 2005 when a limited turbine modification increased its output at lower inlet pressures by 2 MW. Since 2008 output has been in decline. In March 2011 the net output increased by 2 MW, as the binary plant came on line. Since 2011 the megawatt output has shown greater seasonal variation. Winter maximum monthly average outputs have recently declined from 14.2 to 12.7 MW. The net capacity factors have also recently declined, in part due to the greater installed capacity (Figure 1).

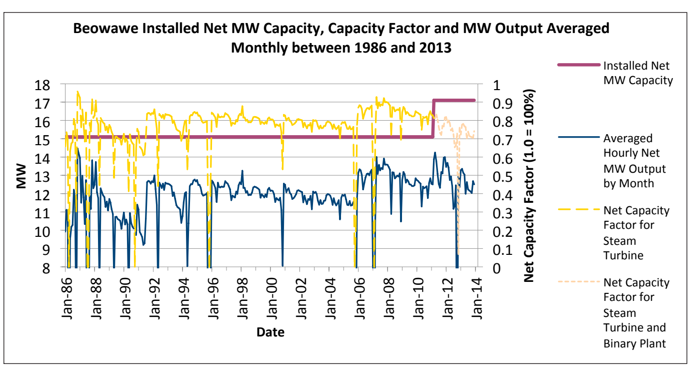

Figure 1. Monthly NDOM production data from the Beowawe geothermal field. The low spikes represent events such as major plant outages or modifications, and times when wells were out of service for carbonate scale clean outs or other repairs. Planned repair work was performed outside of the summer peak price months.

The Beowawe project has operated at close its initial net MW capacity, in spite of fluid-entry temperatures cooling at rates of 7-8 ºF/yr from 410 ºF to as low as 348 ºF between 1988 and 1998. Megawatt declines were as high as 2.66 MW/yr in 1993 (Benoit, 1997). However, during this time reservoir pressures actually increased due to denser cold water recharge into the reservoir (Benoit and Stock, 1993). Increased flow rates due to higher reservoir pressures have compensated for the reservoir temperature decline (Figure 2). In April 2009 injection into the original injector resumed due to increasing production rates and by 2013 about 27% of the total injection stream was back into the original injection well (NDOM, 2013).

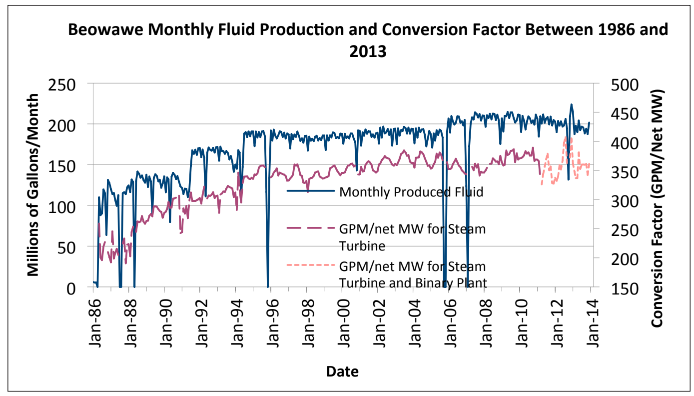

Figure 2. Beowawe monthly production rates and required amount of fluid to produce one megawatt. The Beowawe fluid production numbers are of good quality and show the annual changes in plant efficiency between summer and winter, especially for the years 1995 to 2008.

The project design called for a production rate of 1.254 x 10^6 lbs/hr (±2600 gpm or 172 gpm/net MW) (Table 1) with 13% of this being steam (Elliott, 1986). In 1987 the actual conversion rate was ±225 gpm/net MW. Between 1988 and 2003 monthly average flow rates have basically doubled and the conversion rate increased to ±375 gpm/net MW (Figure 2). Calculated GPM/MW data from Beowawe are accurate enough to show the plant seasonal output variation. Since 2011 a flow rate decline trend has become evident and the GPM/MW numbers show greater seasonal variation with the binary plant in service.

The Beowawe history is a rather remarkable long-term maintenance of MW output. Substantially declining resource temperatures (Benoit, 1997) have been balanced by increased flow rates (pressure) without extensive human intervention such as injection augmentation, pumping, or relocating production wells. Fortunately the short gathering system handled the increased flow rates without costly modifications. Beowawe is a case where plant and resource sizes are well matched; a small power plant sited on a small resource.

Desert Peak

The 9.456 MW net (10.171 MW gross) (Cerini et al., 1985) Desert Peak power plant began operations in the last week of 1985 under the terms of a 10 year demonstration power purchase agreement, with Sierra Pacific Power Company (Faulder and Johnson, 1987). It also received an expiring tax credit. This was the only dual flash plant in the United States to not sell its output into

California and is the smallest of the five flash plants in Nevada. The project was originally developed by Phillips Petroleum but due to plunging oil prices and hostile takeover activities Phillips sold the project to Chevron in 1986 as part of the Western States Geothermal Company. Chevron in turn sold it to Cal Energy (CE Geothermal, Inc.) in 1990. In May 1996 the original power sales contract expired with no provision for renewal or extension. For 3 years the plant received only 1.98 cents /kilowatt hour under avoided cost pricing. This led to minimal investment in maintaining the plant and steam field. Brady Power Partners, led by Florida Power and Light, began utilizing the Desert Peak power to cover parasitic load losses at Bradys in Sept. 1999 after building a 4 mile-long transmission line between the two plants. In 2001 Ormat purchased the Desert Peak project from Cal Energy and continued sending the Desert Peak output through the Bradys plant until Jan. 2007. Ormat now sells the Desert Peak power directly to NV Energy.

At startup the plant was supplied by two closely-spaced artesian production wells with resource temperatures of 406 ºF. All injection was into one well. The project design was for 1 x 10^6 lbs/hr (2000 gpm or 212 gpm/net MW) and included a 2 cell wet cooling tower. Total measured flow rate from the two wells was initially 0.98 x 10^6 lbs/ hr. During the first year of production there apparently were some production temperature increases of 2 – 5 ºF and no pressure depletion (Faulder and Johnson, 1987).

The original Desert Peak power plant included a 656 kw rotary separator turbine power skid upstream of the dual stage Delaval steam turbine to increase the power plant output. Unfortunately, the rotary separator turbine was not successful and was removed from the power station in 1987(?) with no obvious loss of plant output.

The Desert Peak project operated with its three startup wells until Feb. 2004 when a preexisting well was placed in service as a third artesian production well. Another preexisting well was also placed in injection service in Feb. 2004. Ormat commenced an extensive step out drilling program in the area with the intent of expanding the field output to 40 MW. This drilling resulted in 2 new pumped production wells being placed in service when a new 18.8 MW net (21.8 MW gross) binary plant started up in Aug. 2006 (Figure 3). Two more new production wells began operating in Jan. 2010 in the first major expansion of the production area. An extensive EGS effort has resulted in a third injection well becoming available for service in 2013. The project now has 7

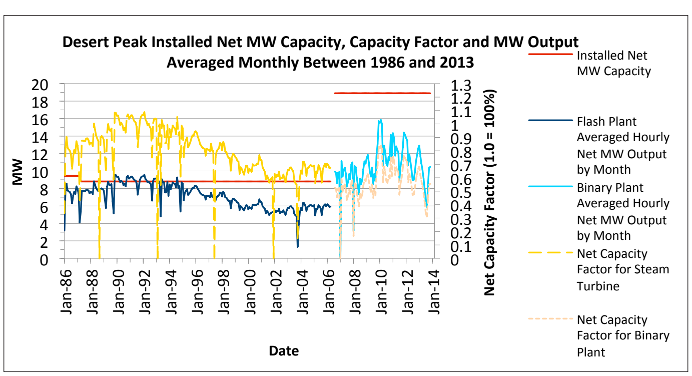

Figure 3. Desert Peak monthly production over time as both flash and binary projects.

active production wells, both pumped and artesian, and 2 active injectors (Table 1). There have been no changes to the Desert Peak injection well locations or injection strategy over time. In 2013 the average Desert Peak production rate was 4200 gpm, a doubling of the original flash plant production rate.

The Desert Peak output initially peaked at 9.5 MW in the early 1990s with net capacity factors as high as 109% (Figure 3). A steady flow rate and megawatt decline began in 1992 leading to as little as 5.0 MW net being generated by 2001. Monthly production rates declined from 117 to 75 x 10^6gal/month between 1992 and 2002 (Figure 4). Between 1990 and 2002 the conversion factor showed little or no change indicating no substantial cooling of the resource during this 12 year interval. Since 2002 the reported conversion efficiency has shown sharp and unbelievably large changes suggesting the reported flow rate data had become erroneous. By example, in late 2002 reported flow rates sharply increased (Figure 4) but there was no corresponding change in the MW output or the number of production wells, suggesting this step is simply a change in instrumentation or the reporting methodology. Similarly, placing the third production well in service in Feb. 2004 increased neither the MW output nor the total production rate (Figures 3 and 4).

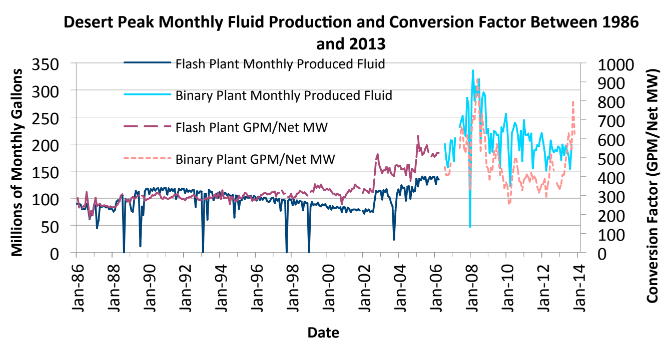

Figure 4. Desert Peak flash and binary plant monthly production rates and required amount of fluid to produce one megawatt.

The binary power plant and additional production wells increased the Desert Peak field output to its all time highest level of 15.8 MW net in Feb. 2010, 25 years after startup. The monthly averaged MW outputs now show a more prominent seasonal variation due to the change from evaporative to dry cooling. Since early 2010 the steepest MW decline trend in the project's history has developed. This trend is defined by both the winter maximum and summer minimum outputs. At Desert Peak a small flash plant operated relatively successfully for 20 years on an apparently small resource with modest resource cooling (Figure 4). With the installation of a medium sized binary plant in 2006 outputs increased but a decline trend is now steadily reducing the plant output.

Steamboat Hills

The 12.5 MW net (13.2 MW gross) single flash Steamboat Hills (SH) plant was commissioned in January 1988 by the Yankee-Caithness Joint Venture (GRC Bull, 1988) with a single 1940s vintage General Electric turbine and a 3 cell wet cooling tower. Earlier exploration and field development in the SH was primarily performed by Phillips Petroleum with a lesser contribution by Gulf Oil. The power is sold to NV Energy. In mid 2004 the plant was sold to Ormat. The Steamboat geothermal field hosts 7 other binary power plants. It is not publicly documented as to what impact the nearby binary plants have on the SH plant.

The project began operations with three artesian production wells with temperatures as high as 450 °F (Walsh et al., 2010) and one injection well. In 2000 a new production well was placed in service but the plant continued to operate with three production wells. The original injection well was replaced in 2005 due to corrosion problems (Land, 2007). In early 2007 the flash plant was integrated with the binary Galena II plant and was then supported by 5 production wells. In Jan. 2010 a sixth production well was placed in service.

The production history of the SH plant shows an ongoing MW decline trend interrupted by step production increases until the flash plant was integrated with the Galena II binary plant in 2007 (Figure 5). After integration, the flash plant shows a more consistent output with seasonal output variation. The large output increase in early 2000 resulted from a new production well coming on line and was the only time the plant met its net nameplate. Smaller output increases before 1997 presumably represent production well cleanouts.

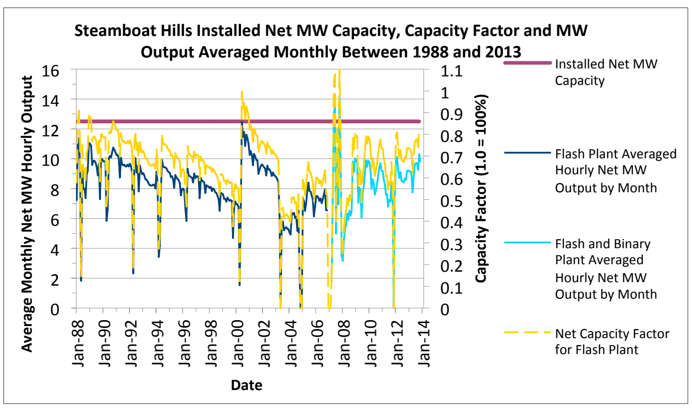

Figure 5. Steamboat Hills monthly plant production over time as both a stand alone flash plant and integrated with a binary power plant starting in early 2007.

The flow rate data from the Steamboat Hills project poorly correlate with the MW output (Figure 6). The saw tooth pattern of MW output prior to 2007 on Figure 5 must represent flow rate changes as geothermal field temperatures do not show sharp reversible changes. These flow rate data are of questionable quality and cannot be utilized to give an indication of temperature changes in the wells supplying the Steamboat Hills power plant. However, the simple fact that up to six wells now provide the megawatt output that formerly required only three wells is evidence of significant temperature and/or pressure decline in this part of the Steamboat resource. On the positive side, since 2009 the Steamboat Hills plant has been consistently producing about 10 MW net during the winters and the production/injection strategy for this plant has not significantly changed since startup.

The small Steamboat Hills flash plant has the advantage of being supported by a resource that has been capable of producing over 100 MW. This means that its fate will largely be determined by the larger adjacent binary plants.

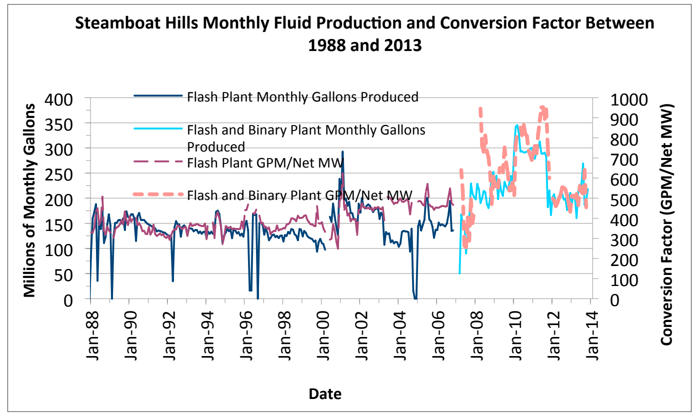

Figure 6. Steamboat Hills flash plant monthly production rates and required amount of fluid to produce one megawatt.

Dixie Valley

The dual flash Dixie Valley power plant was commissioned in July 1988 with a single 60.5 MW Fuji turbine (Fuji Electric) and a seven cell cooling tower that evaporates ±1600 gpm. At startup the intent was to operate at 56 MW gross to deliver 49.8 MW to Southern California Edison. However, it quickly became evident the project could deliver more electricity so additional wells were drilled to increase the sustainable output to 56 MW net (62 MW gross) as SCE was willing to purchase the additional power. The production history shows the turbine nameplate of 60.5 MW is unrealistically low as the project consistently operated at ±62 MW gross and achieved outputs as high as 67.6 MW gross. A nameplate value of 56 MW net is therefore utilized as it was the target output.

Exploration at Dixie Valley was dominated by Sun Oil Company with Trans Pacific, Southland Royalty, Republic, and Chevron playing lesser roles. Trans Pacific, with a small overall lease position in the area, had the foresight to acquire 40 MW of high-price Standard Offer #4 Contracts from Southern California Edison. Oxbow Corp. purchased and consolidated the Sun and TransPacific lease positions and power sales contracts totaling 49.8 MW to create a financially viable project with the longest privately owned transmission line in the country. Oxbow drilled 4 additional wells in 1986 and in mid 1988 completed the plant along with a 220 mile-long 220 kV transmission line to deliver power to Southern California Edison at Bishop California. Oxbow sold the project to Caithness in 2000 and Caithness sold it to Terra-Gen Power LLC in 2007.

Dixie Valley is the hottest producing geothermal field in Nevada. For the first few years of operations the Dixie Valley power plant was the largest dual flash power plant in the world. With an injection rate of 10,000 gpm it was also one of the first large-scale geothermal injection projects in the world. It is the only geothermal project in Nevada to augment its injection with cold ground water (Benoit et al., 2000).

The field started production with six 480 °F production wells in two widely spaced clusters and 4 injection wells. Three production wells were completed with 9 5/8" casing and three with 13 3/8" casing. Three additional injectors were placed in service in 1989 and one in 1990 (Benoit, 1992). By 1990 there were 8 injectors in service. Between 1988 and 1997 five 13 3/8" production wells were drilled and one was deepened to increase the net output from 49.8 to 56 MW (56 to 62 MW gross) and to replace production from three 9 5/8" wells that could no longer supply fluid at the wellhead pressures generated by the 13 3/8" wells. All of the larger diameter production wells were drilled within the original two production areas. One 13 3/8" well was removed from service in 2001 due to damage sustained during a workover. In 1997 an injection augmentation program to make up for cooling tower evaporation losses was placed in service. This program has been so successful in sustaining the reservoir pressure that no new production wells have been drilled since 1997. Two shallow injection wells were drilled in 2000 with the specific intent of returning injectate to the northern production wells and one of these injection wells had to be sidetracked in 2009 (Land, 2009). All of these activities were undertaken in a timely manner so that the project output never established a long-term decline trend. In 2013 a total of 11 dispersed injection wells and 8 production wells were in service (Benoit, 2013). The overall production and injection layout of the field was only modestly changed since startup.

Multiple changes were made to the plant and gathering system over the years including; installation of vacuum pumps on the condenser to free up high pressure steam for power generation, a major modification of the turbine to operate at lower pressures, removal of master wellhead valves and installation of sweeping elbows on wellheads to reduce pressure drops, and installation of an additional low pressure separator and pipeline in 2009 to allow a smaller diameter well to again be utilized for production in the lower pressure part of the turbine. In Oct. 2012 Terra-Gen power started up a 5 MW net (6.2 MW gross) air cooled TAS binary power plant on the Dixie Valley injection line.

The Dixie Valley power plant has had a reasonably steady MW output since 1990, with the exception of a major transmission line repair for damage due to an ice storm in 2008 (Figure 7) and well workovers in 2009 and 2010. The largest positive change in 2004 reflects the major turbine modification to operate at lower pressure. In 2013, with a full year of operation of the binary power plant the total Dixie Valley output was close to its all time high but increases have not been consistent on a monthly basis.

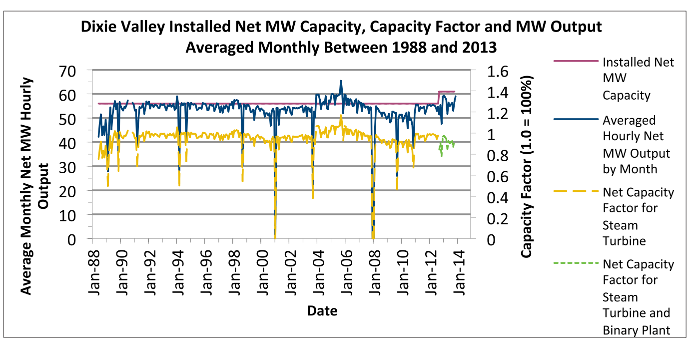

Figure 7. Monthly NDOM production data from the Dixie Valley geothermal field.

Over time there has been a modest increase in the average monthly fluid volume produced at Dixie Valley and in the conversion factor (Figure 8). In the mid 1990s about 10,500 gpm were produced. In 2013 about 12,300 gpm were being produced. The conversion factor has increased from a low of 190 gpm/MW to 230 gpm/MW indicating modest cooling of this resource over time. Obvious upward trends in the conversion factor are present

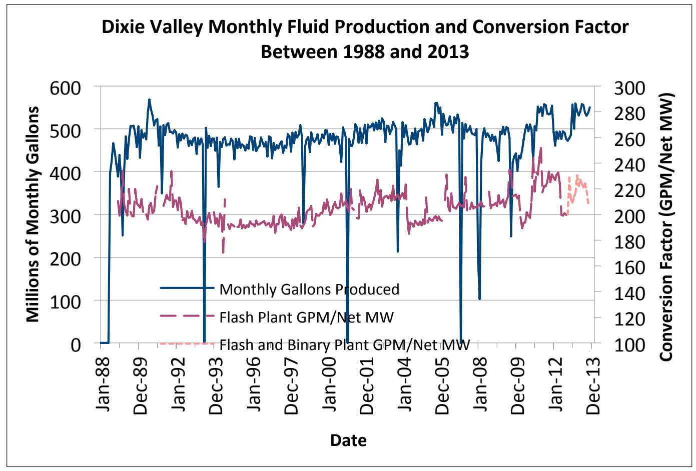

Figure 8. Dixie Valley monthly production rates and required amount of fluid to produce one megawatt.

between 1997 and 2004 and from 2004 to 2012. The sharp reduction in 2004 reflects the major turbine modification.

Dixie Valley is a case where a large plant and a fairly large resource are well matched but it still required 10 years of ongoing wellfield modifications after plant startup to get the resource operating in its current condition and a major turbine modification 16 years after startup to operate at lower pressures. The resource cooling has been modest and reservoir pressures have been artificially maintained with a cold water augmentation program that has eliminated any makeup well drilling for the past 17 years.

Bradys

The Bradys dual flash 20 MW net (26 MW gross) power plant commenced operations in May 1992 with three 1940's vintage General Electric turbines, three generators, and a 3 cell wet cooling tower. Two turbines operate at higher pressure, and one at lower pressure (Ettinger and Brugman, 1992). The project was built by Brady Power Partners, a partnership of ESI Energy, a subsidiary of Florida Power and Light, and Nevada Geothermal Power Partners. The power is sold to NV Energy. Ormat purchased the Bradys project in July 2001.

At startup in 1992 the project had eight 355 °F closely-spaced pumped production wells and 4 closely-spaced injection wells. The design production rate was 5.8 x 10^6 lbs/hr (11,600 gpm and 580 gpm/MW) making it a larger-volume project than Dixie Valley. Within one year of startup the average production temperature had declined by 36 °F, sharply reducing the plant output (Figure 9) (Krieger and Sponsler, 2002). Between early 1993 and 2000 a complex sequence of field modifications, involving both production and injection wells, were undertaken to increase the plant inlet temperatures, reduce the cooling rate, and maintain the production. The most notable involved drilling two new deeper and hotter production wells, four new injectors, and construction of a four mile-long injection line to export up to 100% of the injectate outside of the Bradys production reservoir (Land, 2012, Krieger and Sponsler, 2002). This is the only place in Nevada, other than the surface discharge at Wabuska and 27% of the flow at Beowawe, that geothermal fluid is intentionally being exported from a reservoir. During 2013 the project had five production wells in service and three active injectors making it the only flash project that now has fewer producers and injectors in service than at startup. Only one of the eight original production wells remains in service. The 2013 year end production well temperatures ranged from 262 to 292 ºF (NDOM, 2013), a maximum decline of almost 100 ºF.

Within the power plant, modifications to more efficiently utilize the steam included modifying the low pressure turbine, changing injection and production well pumps, and reducing the high-pressure steam flow to the steam ejectors. In 2002 Ormat installed a 5.23 MW gross (4.41 MW net) binary power plant with air cooled condensers on the injection line. This was an improvement guaranteed to have a large impact as the injectate stream from the low pressure separator had a temperature of 231 ºF and the design outlet temperature from the binary plant was 180 ºF.

The production history at Bradys is abnormally complex due to the importation of Desert Peak power to offset the parasitic losses between Sept. 1999 and Jan. 2007 (Figure 9). The Desert Peak power artificially boosted the reported Bradys net output. Subtracting the Desert Peak output gives a more realistic approximation of the actual Bradys outputs during this time (Figure 9). Bradys output trend has consisted of nearly continuous decline, except for the increase in 2003 due to the start of binary plant operations. All the field and plant modifications undertaken between 1993 and 2000 could not overcome the declining temperatures and did not stabilize the plant output. Now more than half of the total power from Bradys may be derived from the binary plant but for a few years it was the second largest Nevada flash plant in terms of net output.

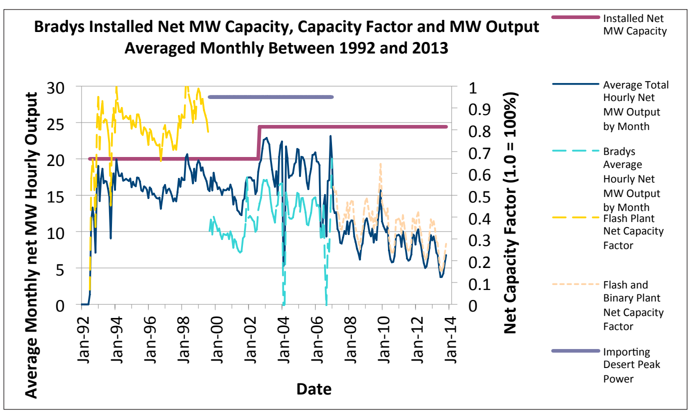

Figure 9. Monthly NDOM production data from the Dixie Valley geothermal field showing when production was imported from Desert Peak.

The production rate from Bradys has substantially declined over time with some short-term step increases as deeper and hotter replacement wells were put in service (Figure 10). The conversion factor at Bradys started out at about 700 GPM/net MW and declined as hotter replacement wells produced more of the fluid. Since 2006 the conversion factor has rapidly climbed so that it is now consistently over 1000 gpm/net MW and the annual variation in the factor is also close to 1000 gpm/net MW as the production temperatures continue to decline.

Bradys experience can be described as a large sized plant, in terms of volume produced, being constructed on a small resource. No amount of field or plant reconfiguration has compensated for installing a large project on a relatively small resource (Benoit, 2013).

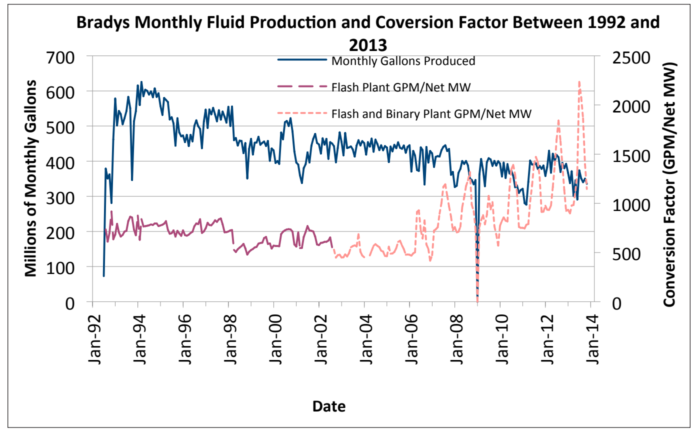

Figure 10. Bradys monthly production rates and required amount of fluid to produce one megawatt.

Project Comparisons

The simplest comparison of the relative project performances is with net capacity factors (Figure 11). Beowawe and Dixie Valley have had the highest and most consistent capacity factors. It took considerably more effort at Dixie Valley to maintain the capacity factor but it also needs to be remembered that the Dixie Valley output is four times that of Beowawe. Recently the Beowawe capacity factors have declined to those of Steamboat Hills.

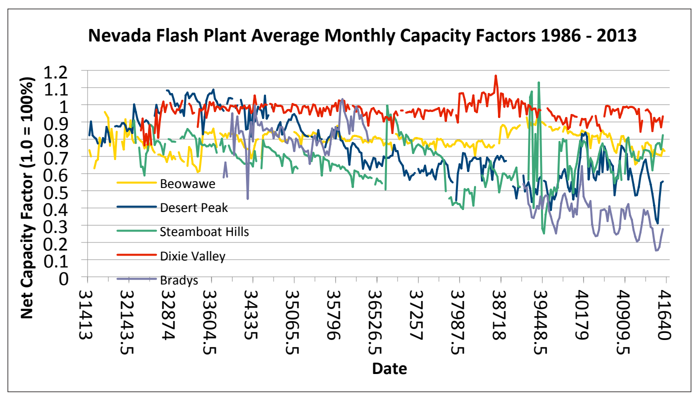

Figure 11. Monthly net capacity factors over time of the Nevada flash plant projects. The high spikes for Steamboat Hills in 2007 are questionable.

In the 1990s Bradys, Steamboat Hills, and Desert Peak showed strikingly similar capacity factor decline rates. However, the Bradys and Steamboat declines started during the first year of operations while the Desert Peak decline began after 7 years of production. It is now necessary to determine the Desert Peak and Bradys declines from their summer minimum and winter maximum outputs due to their now greater seasonal variations as these are mostly or all binary plants.

A second comparison of the fields is of their conversion factors against each other and over time (Figure 12). Dixie Valley has had the most consistent conversion factor and therefore the least amount of resource cooling. Beowawe now has the second lowest conversion factor but it has almost doubled since 1986. Once the Bradys, Steamboat, and Desert Peak plants largely became binary projects their conversion factors have shown much greater changes between summer and winter. In the summer of 2013 it took about 10 times as much fluid at Bradys to produce one megawatt as it did at Dixie Valley due to Bradys now producing the coolest water of these projects.

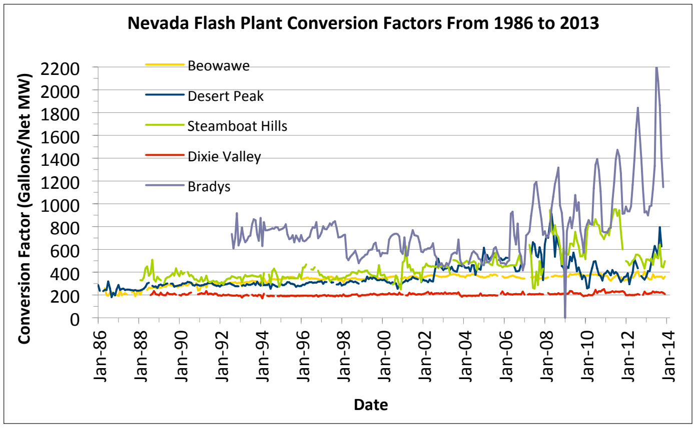

Figure 12. Nevada flash plant conversion factors over time.

A graph of cumulative production over time shows that the Dixie Valley field has generated more electricity than all of the four other plants combined from startup through year 2012 (Figure 13). Given the declines now occurring in the Beowawe, Desert Peak, and Bradys fields this trend should continue in future years. The Beowawe plant has now produced slightly more cumulative power than Bradys and this spread should increase in coming years, especially since Desert Peak power is no longer run through the Bradys plant. Desert Peak and the Steamboat Hills plants have produced very similar amounts of power over the years.

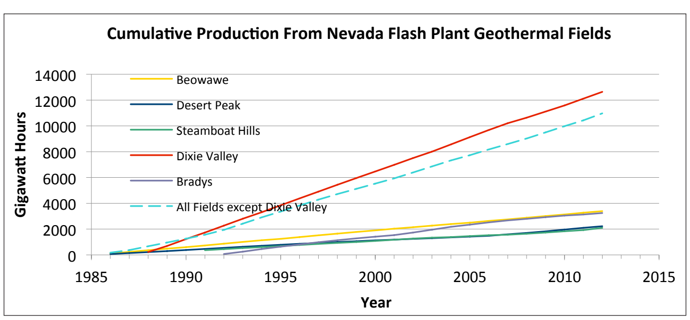

Figure 13. Cumulative production from the Nevada flash plant projects.

Table 1.

Field and Startup Year	Initial Resource Temp. ºF	Net MW Nameplate at Startup	No. of Active Prod. Wells at Startup	Design Flow Rate (gpm)	Design Gpm/MW	No of Active Inj. Wells at Startup	2013 Installed Capacity Gross	2013 Ave MW Net Output	2013 No. of Active Prod. Wells	2013 Annual Average Flow (gpm)	2013 GPM/net MW	2013 No of Active Inj. Wells	Maximum Average Net Monthly Output And (Year)
Beowawe 1985	410	15.1 MW DF	2	2600	156	1	19.16 DF+B	15.0	3	4500	300	2	14.47 (1986)
Desert Peak 1985	406	9.46 MW DF	2	2000	196	1	21.8 B	12.7	7	4200	331	2	15.83 (2010)
Dixie Valley 1988	480	49.8 (56)MW DF	6	11,100	179	4	67 DF+B	63.0	8	12,400	197	11	65.48 (2005)
Steamboat Hills 1988	≤442	12.5 MW SF	3	?	?	1	13.2 SF	10.8	6	4763 max?	441	2	12.45 (2000)
Bradys 1992	355	20 MW DF	8	11,600	580	4	31.23 DF+B	11.5	5	7800	>1000	3	20.64* (1998)

DF=dual flash, SF=single Flash, B=binary
*This is power from only the Bradys turbines.

Conclusions

Each of these projects has had a unique history, ownership, and challenges as well as some commonality. All the projects started out as flash plants but now have binary components ranging from 8 to 100% of the net capacity. This binary component has significantly reduced the injectate temperture. Cooler injectate increases the heat mining load on these resources and must eventually result in accellerated production temperature decline rates unless well locations are changed. All of the projects have suffered varying amount of resource cooling, which has not been recently publicly documented. This cooling has led to increased production rates per megawatt of output. Dixie Valley has had the least cooling and Bradys, which had the lowest resource temperatures of the group at startup, has unfortunately suffered the most cooling. At Beowawe naturally increasing flow rates have to a great extent compensated for the cooling while at Dixie Valley augmentation of injectate with cold groundwater stabilized the field output volume.

From a capacity factor perspective the Beowawe and Dixie Valley projects have been the most successful as the plant and resource sizes have been complimentary, a large plant and field at Dixie Valley and a small plant and field at Beowawe. Steamboat Hills has also been successful being a small plant on a large but shared resource. Bradys has a large power plant on a small resource, giving it the lowest capacity factors. Desert Peak is a case where a small plant operated relatively successfully on a small field given an unfavorable power sales agreement after the first ten years of operations. The Desert Peak field hit an all time MW output high 25 years after production began, but field has since been challenged to maintain the required production increase for the medium sized plant. The Desert Peak dual flash plant is the only flash project in Nevada to be decommissioned.

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References

Benoit, W. R., and Butler, R. W., 1983, A review of high-temperature geothermal developments in the northern Basin and Range Province, Geothermal Resources Council, SPECIAL REPORT NO. 13, May 1983, pp. 57 – 80.

Benoit, D., and Stock, D., 1993, A case history of injection at the Beowawe, Nevada geothermal reservoir, Geothermal Resources Council *Transactions*, Vol. 17, pp. 473 – 480.

Benoit, D., 1997, Injection-driven restoration of the Beowawe geothermal field, Geothermal Resources Council *Transactions*, Vol. 21, pp. 569 – 575.

Benoit, D., Johnson, S., and Kumataka, M., 2000, Development of an injection augmentation program at the Dixie Valley, Nevada geothermal field, Proceedings World Geothermal Congress 2000, pp. 819 – 824.

Benoit, D., 2013, An empirical injection limitation in fault-hosted Basin and Range geothermal systems, Geothermal Resources Council *Transactions*, Vol. 37, pp. 887 – 894.

Cerini, D. J., Diddle, C. P., and Gosner, W. C., 1985, Desert Peak 9 MW power plant, Geothermal Resources Council BULLETIN, February 1985, pp. 3 – 8.

Dickey, H. K., Forsha, G., Forsha, M., and Linden, B., 2011, A new high efficiency binary expander design: low temperature geothermal application bottoming Beowawe geothermal flash plant, Geothermal Resources Council *Transactions*, Vol. 35, pp. 1295 – 1299.

Edmiston, R. C., and Benoit, W. R., 1984, Characteristics of Basin and Range geothermal systems with fluid temperatures of 150 ºC to 200 ºC, Geothermal Resources Council *Transactions*, Vol. 8, pp. 417 – 424.

Elliott, L.T., 1986, Beowawe 16MW Geothermal Power Plant Project Chevron Geothermal Company/Crescent Valley Energy Company, Proceedings of a Topical Meeting on Small Scale Geothermal Power Plants and Geothermal Power Plant Projects, Meeting Sponsored by Geothermal Resources Council in Reno, Nevada, February 12-13, 1986, p. 83-97.

Ettinger, T., and Brugman, J., 1992, Brady Hot Springs geothermal power plant, Proceedings, 14th New Zealand Geothermal Workshop, pp. 89 – 91.

Faulder, D. D., and Johnson, S. D., 1987, Desert Peak geothermal field performance, Geothermal Resources Council *Transactions*, Vol. 11, pp. 527 – 533.

Fuji Electric, undated, Geothermal power plant brochure Dixie Valley geothermal power plant, 5p.

Geothermal Resources Council BULLETIN, 1988, Yankee/Caithness starts-up their first power plant, Geothermal Resources Council Bulletin April 1988, pp. 3 – 5.

Krieger, Z., and Sponsler, E., 2002, Improvement to the Brady geothermal project to compensate for decline in resource performance, Geothermal Resources Council *Transactions*, Vol. 26, pp. 735 – 738.

Land, R., 2007, UIC Permit Fact Sheet (for Ormat Nevada), Nevada Division of Environmental Protection, 7p.

Land, R., 2009, Fact Sheet (for Dixie Valley Geothermal Project), Nevada Division of Environmental Protection, 3 p.

Land, R., 2012 UIC Fact Sheet (for Brady Power Partners), Nevada Division of Environmental Protection, 5 p.

Land, R., 2013, Fact Sheet (for Beowawe Geothermal Power Company), Nevada Division of Environmental Protection, 4 p.

Mitsubishi, undated, Beowawe double flash cycle geothermal power plant, brochure 6 p.

NDOM, 2013, Monthly production reports.

Shevenell, L., Price, J. G., and Hess, R. H., 2012, Data tables and graphs of geothermal power production in Nevada, 1985-2011, Nevada Bureau of Mines and Geology Open-File Report 12-3, 19 p.

Walsh, P., Martini, B. A., and Spielman, P., 2010, High angle fracture-controlled permeability at Upper Steamboat Hills Geothermal Field, NV, Geothermal Resources Council *Transactions*, Vol. 34, pp. 833 – 837.