Four Decades of Service – Kızıldere Reservoir, Units and Management

Ural Halaçoğlu[1], Matthew Fishman[2], Ulaş Karaağaç[1] and William Harvey[2]

[1] Zorlu Enerji, Istanbul, Turkey

[2] POWER Engineers, Inc., Hailey Idaho U.S.A.

Keywords

Kızıldere, Turkey, reservoir management, project development, operations

ABSTRACT

The Kızıldere resource in the Menderes graben is one of the oldest and largest developed fields in Turkey for power generation. The first permanent installation, Kızıldere-1, has been operating successfully since 1984, and Kızıldere-2 was commissioned in 2013. The recent completion in 2017-2018 of two units at Kızıldere-3 has brought the current gross generating capacity of the field to over 250 MW, utilizing a total of 42 production and 28 injection wells. This paper discusses the ever-evolving geoscientific understanding of the field, presents characteristics of the various generating units and describes the building up of human capacity by the developer and operator, Zorlu. The paper includes metrics on the drilling programs, plant performance, staffing, achievable project timelines given Zorlu's proven delivery methods and key lessons learned from each development. Current operational assessment and testing practices are detailed in relation to resource sustainability efforts. Plans for future expansion and management are outlined, based on the latest geoscience and well testing.

1. Introduction – Kızıldere Overview

Turkey's geothermal power sector has recently surpassed 1,150 MW of generation capacity to become the fourth highest in the world, only trailing the United States, the Philippines and Indonesia (Richter 2018). Almost all of this development has occurred since 2008, when Kızıldere-1 (the only operating power geothermal plant in Turkey at the time) was privatized. It has also centered around the western Anatolia region of the country due to the area's favorable geology.

Situated in the southeast Aegean region of Western Anatolia, the Kızıldere field is one of the most well characterized and developed geothermal resources in Turkey and has a rich history of geothermal power extending back as far as 1974. In addition to the field housing the oldest operating plant in the country, it also contributes about a quarter of the overall installed geothermal electrical power capacity of Turkey. Zorlu's operations contribute 260 MW to the field's capacity, with additional capacity planned in the near future. As of March 2018, Zorlu holds the highest installed capacity in the overall Turkish geothermal market per Turkey's Energy Market Regulatory Authority (EMRA) data, shown in Figure 1.

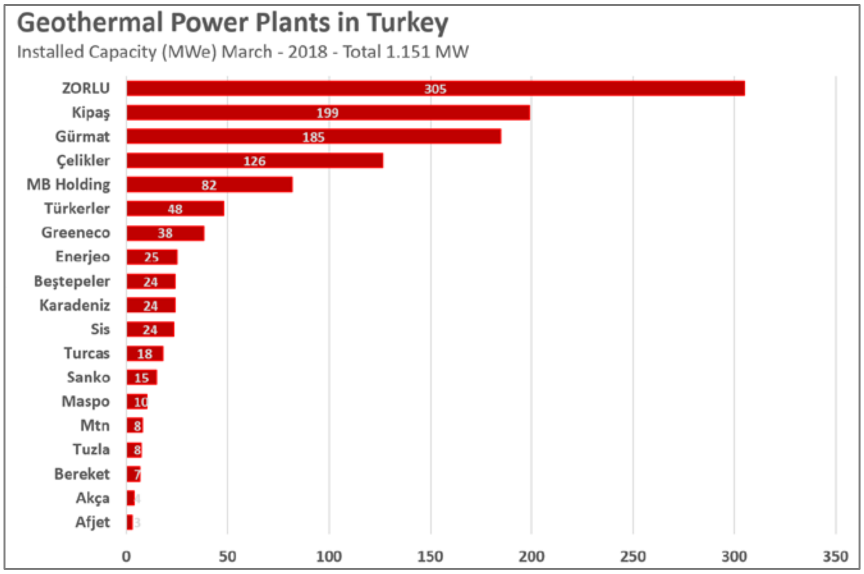

Figure 1: Geothermal installed capacity in Turkey by company distribution (EMRA 2018).

In this paper, we will first provide a review of the geoscientific understanding of the reservoir itself and its many layers. From there, we will proceed to a discussion of the staged development of the reservoir, expanding its use both horizontally and vertically, as well as its integration into the surrounding communities. To conclude, we will point to future exploration and development still to be undertaken.

2. Kızıldere Geoscience – Unpeeling the Onion

The Kızıldere resource spans an area between the Aydın and Denizli provinces in the northeastern region of the Büyük Menderes Graben. A high heat flow in this region produces reservoir temperatures of 200°C at -500m and 240°C below -1200m, which are more than adequate for power generation. Figure 2 shows a conceptual model of the field.

The main reservoir characteristics of the Kızıldere field are defined as follows:

- High temperature, liquid dominated
- High non-condensable gas (NCG) content
- Kızıldere-2 and Kızıldere-3 wells are located at upflow zone
- High horizontal permeabilities along fractures created by intersecting fault system
- Low vertical permeabilities
- Highly effective thermal circulation between injection and production wells (no early breakthrough of injection water)

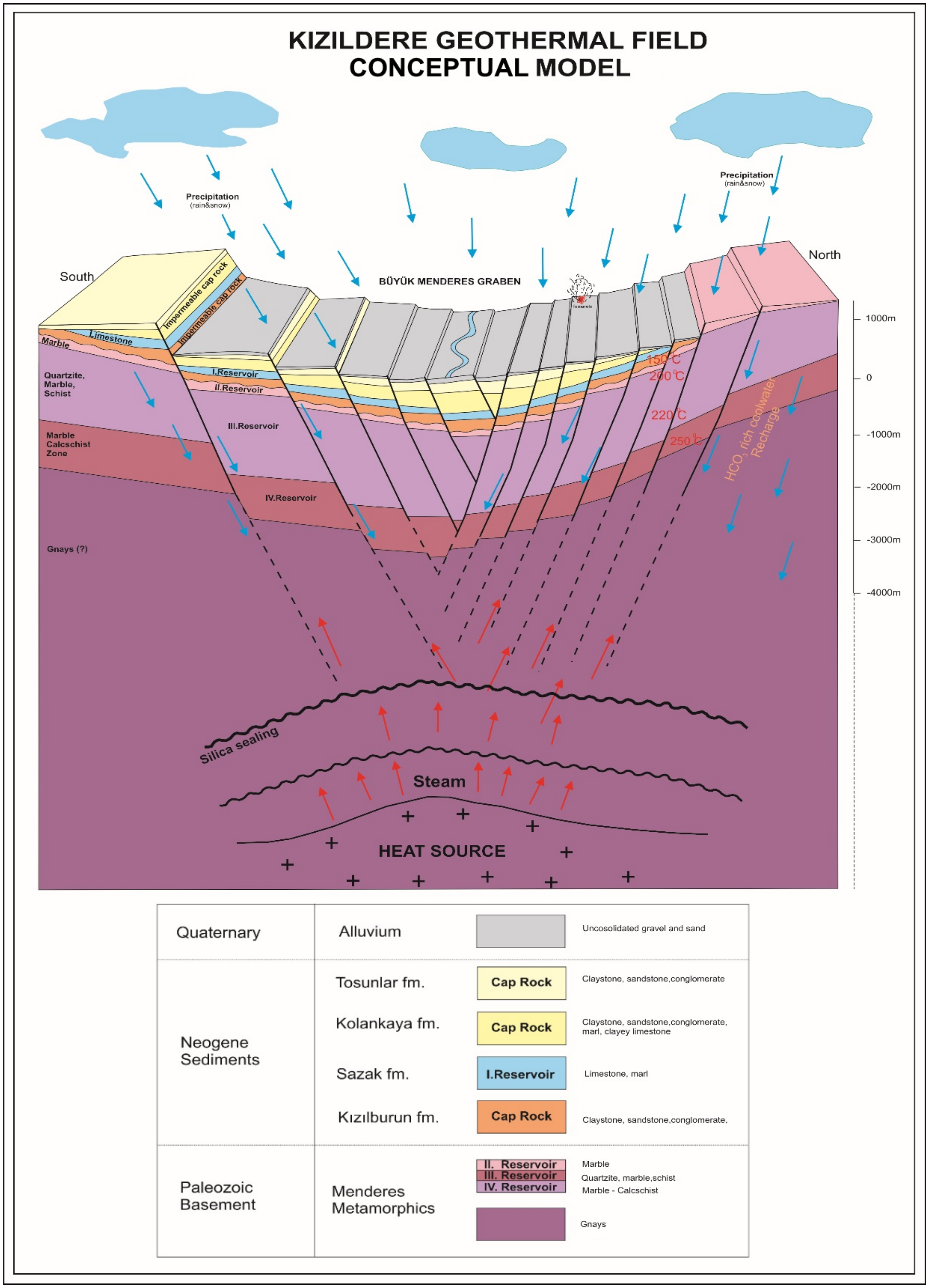

Figure 2: Kızıldere geothermal field conceptual model.

Due to the great potential of the Kızıldere field and the extensive surveying and modeling performed over the years, there have been around 90 wells drilled so far and the drilling success rate is higher than many regions worldwide. Table 1 shows recent wellfield development and the well characteristics observed in the Kızıldere field.

Table 1: Drilling results and well characteristics of Kızıldere field.

	NUMBER OF PRODUCTION WELLS	DEPTH (M)	STATIC TEMP (°C)	FLOWRATE (TPH)
KIZILDERE-1	7	400-900	200-215	110-360
KIZILDERE-2	11	1900-3050	215-242	175-300
KIZILDERE-3 U1	14	2600-3450	210-245	100-300
KIZILDERE-3 U2	10	3100-3500	205-241	100-250
	NUMBER OF WELLS	DEPTH (M)	WHP (BARG)	FLOWRATE (M3/H)
COMMON RE-**INJECTİON**	28	550-3450	0.5-36	50-550

3. A Deliberate Development Strategy – Zorlu's First Four Units

Zorlu's vision for the development of the Kızıldere field began in 2008 with the acquisition of the operating Kızıldere-1 plant and geothermal concession area from the utility company Electricity Generation Co. Inc. (EÜAS). The privatization of the operating license allowed Zorlu to quickly implement a strategic plan for phased exploration, assessment and development of the resource that focused on specific short, mid, and long-term goals (Kindap et al 2009).

By following this process, Zorlu has been able to verify the necessary field capacity to expand their operations several times since the initial evaluation. As of 2018, Zorlu's Kızıldere portfolio includes four operating units with several future plants under consideration:

1. KZD-1
2. KZD-2
3. KZD-3 Unit 1
4. KZD-3 Unit 2
5. *KZD-4 (future)*
6. *Tekkehamam (future)*

Other plants nearby operated by entities such as Bereket, GreenEco and Limgaz are also acknowledged, but commentary on those developments is reserved for those owners.

With each additional plant, new strategies for reservoir management and field-wide upgrades are identified and implemented to ensure the expansion process is successful. In this section, we will focus on aspects of project development and how responsible reservoir management practices have aided in the successful expansion of the Kızıldere field.

3.1 Kızıldere-1 (KZD-1)

The Kızıldere-1 geothermal power plant (GPP) has the honor of being the oldest operating geothermal power plant in Turkey. In operation since 1984, this 15 MW single flash plant was installed by EUAS at the conclusion of a pilot study in the field (Kindap et al 2009). That study was an effort championed by the General Directorate of Mineral Research and Exploration (MTA) to research and develop the field. A 0.5 MW pilot plant was installed in 1974 and operated until 1980, all the while providing free electricity to the nearby village.

The shallower reservoir tapped for Kızıldere-1 production wells provided downhole temperatures ranging from 160°C to 200°C. This reservoir contained a relatively high non-condensable gas (NCG) percentage in the flashed steam compared to flash plants worldwide; around 1.7% in the geofluid, which necessitated a similarly large NCG removal system. In this case, the original plant design by ENEL incorporated a gear-driven compressor, similar to other Italian designs at Lardarello. It is notable that this machinery has operated well over the years, no doubt due to a rugged design, but also in part perhaps due to the relatively low content of corrosive H_2S in the geofluid.

While Kızıldere-1 jump-started Zorlu's geothermal portfolio, the plant was suffering from reduced performance at the time of acquisition. Calcium carbonate scaling in the production wells had reduced operating capacity to just under 6 MW. To rectify the performance issues, the wells were mechanically cleaned and an intense testing program was implemented to determine the most effective method of scale mitigation. The chemical injection systems that were installed at the wellheads allowed testing and verification of many inhibitors and the successes achieved at the Kızıldere field have served as a model for similar wells throughout Turkey. We view this at-the-time, single-digit MW success in developing an effective anti-scalant dosing program as being instrumental in Turkey eventually being able to join the 1 GW geothermal club ("Mighty oaks from little acorns grow").

Additional strategic plant upgrades have taken place over time to increase the reliability and stability of the plant and production system. These include implementing modern instrumentation and controls in the power plant and wellfield, and upgrades to the separation and wellhead equipment, piping and instrumentation. New seismic code structural reinforcement has been carried out on the four-cell concrete wet type cooling tower by upgrading each cell individually without interrupting the operation of the remaining cells (see Figure 3). The turbine and compressor have also received an overhaul in the form of bearing and coupling alterations and sandblasting, the wells have undergone cleaning and workover studies, and various building remodeling projects have improved operability and operator safety.

There was only one reinjection well until the privatization of the field by Zorlu Energy. R-1 was the first well to be drilled in 1998 for reinjection, but it was discovered to be the highest temperature well of the field and subsequently turned into a production well in 2001. Afterwards, the R-2 well in 2002 and R-3 well in 2006 were drilled for reinjection purposes by EÜAŞ, but only R-2 was used for reinjection with 150 tph capacity. Additional reinjection wells were drilled during the early phases of the takeover to increase injection capacity to 900-1000 tph, which meant full reinjection capacity was eventually achieved. It was succeeded with the addition of two more reinjection wells (KD-1 and KD-2) and a reinjection pump station (Figure 4).

Figure 3: KZD-1 cooling tower before and after retrofit.

Figure 4: First reinjection pump station in Kızıldere field.

3.2 Kızıldere-2 (KZD-2)

The transition of the field also provided Zorlu with enormous amounts of data collected over decades of exploration and research by both public and private organizations. With the assistance of experienced consultants, a comprehensive feasibility study was performed on the field to determine the appropriate size and scope of future expansion. Performing a feasibility study allowed Zorlu to confidently plan for and execute the next stage in development with less risk to major stakeholders.

Once the reservoir characteristics were established through reservoir modeling, it became clear that distinct zones were present with different temperatures at varying depths and locations in the field. Segregating the field into production and injection areas by their temperature and permeability has enabled Zorlu to sustain reservoir temperatures and pressure while limiting interference between production and injection wells. This strategy was carried forward and applied to the Kızıldere field on a larger scale to facilitate planning for future stages of expansion.

After considering air-cooled binary and water-cooled flash designs in the feasibility study, the original Phase II development strategy was laid around a 60 MW triple flash plant. During the initial preparation of the conceptual design, led by POWER Engineers, the cycle design was modified to an innovative water-cooled combined cycle design coupling a steam turbine with bottoming binary units. This also allowed the project size to be increased to 80 MW. This type of plant was a desirable match for the high enthalpy, high NCG reservoir and resulted in a higher efficiency and better utilization of the geofluid than traditional single-cycle plant designs. Additional details of the Kızıldere-2 design can be found in Lewis et al (2015) and Tamaya and Muto (2014).

The Kızıldere-2 plant can be considered a “five-in-one” power plant and we can list the benefits it provides under five main categories:

1. Electricity Generation

While the Kızıldere-I geothermal power plant (GPP) (with 15 MW capacity) generated an average of 110 million kWh of electricity annually, with the addition of the new Kızıldere-2 power plant, Zorlu managed to achieve a total of 95 MW and an annual 650 million kWh of electricity from renewable resources. Kızıldere-2 GPP’s electrical output corresponds to the annual electricity consumption of 400,000 residential houses.

2. Pure Carbon Dioxide and Dry Ice Production

Today, the power plant also contributes to domestic and regional economies by contributing to the production of commercial CO_2, which finds many uses across several industries. In order to reduce and economically evaluate carbon emission in Kızıldere site, Zorlu supplies a considerable amount of CO_2 (which is found naturally in geothermal fluids) to a nearby pure carbon dioxide and dry ice factory, achieving a symbiosis of technologies. Thus, no additional sources and/or fossil fuels such as coal or natural gas are used for producing CO_2, which is the main raw material for dry ice. This helps deliver economic and environmental benefits for the region.

3. District Heating System

Kızıldere-1 power plant provides free district heating for 2,500 residential houses in the Sarayköy district of Denizli province by supplying the required geothermal separated liquid to the Bereket Energy facility near Kızıldere-1. The Kızıldere-2 plant also has an installed district heating capacity for 10,000 residential houses at the ready.

4. Greenhouse Cultivation

The Sarayköy district of the Denizli province (near Buharkent district), where the Kızıldere geothermal power plants are located, is famous for its intensive monoculture fig agriculture. This presents risk management challenges for local farmers. In order to eliminate the disadvantages of yearly crop price changes and monocultural agriculture applications, the region is appointed as an Organized Greenhouse Area (OGA) in the Denizli Province Master Plan. This designation encourages local farmers to grow alternative crops, some of which are grown in greenhouses. One of the biggest expenses in utilizing greenhouses for cultivation is the heating cost. Fortunately, some of Zorlu's geothermal resources are allocated to solving this problem for the local agriculture industry. Zorlu's Kızıldere facilities provide geothermal waters needed for heating 500 hectares of vegetable greenhouses within the OGA free of charge. With the heat energy provided to the organized greenhouse area, an annual total of 15 thousand tons of vegetable production can be achieved in the central region and this production yield can be further increased by using refined CO_2 gas in cultivation.

5. Thermal Tourism

The presence of Kızıldere GPP has created a new employment area for the local economy by kick-starting thermal tourism in the region. Thermal tourism is also supported by providing free geothermal waters to three hotels which were built as part of a thermal tourism initiative.

3.3 Kızıldere-3 Unit 1 (KZD-3U1)

Continued efforts by Zorlu's development group to explore, map and test the reservoir prompted additional expansion activities after the completion of Kızıldere-2. As the resource had already been proven by this point, the Kızıldere-3 feasibility study was focused on the technologies available to efficiently harness the resource. Once again, the options were narrowed down to a triple-flash combined cycle arrangement to match the high enthalpy of the deeper reservoir. Experience has shown that this type of cycle can provide the best "bang for the buck" when compared to other types of plants on a net production per unit of geofluid. Table 2 shows the design specific net power output (net power per unit of geofluid) of the Kızıldere plants compared to other reference plant types for the same resource characteristics. The water cooling also allows higher output in hot summer conditions compared to air-cooled units.

Table 2: Specific net power output of high enthalpy, high NCG plants.

OPERATING PLANTS	DESIGN SPECIFIC POWER OUTPUT GEOFLUID USE (kWn/tph)
Kızıldere-1 – single flash	11-13
Kızıldere-2 – triple flash, combined	25.4*
Kızıldere-3U1 - triple flash, combined	27.9
Kızıldere-3U2 - triple flash, combined	26.5
REFERENCE PLANTS	
Double flash – traditional	14-16
Double flash – combined cycle	21-23
Binary	19-24

*Note: Flow also received from Kızıldere-1 lower enthalpy reservoir.

Unlike Kızıldere-2's all top-exhausting turbine design, the Kızıldere-3 turbine has a top-exhausting HP section and an axial exhaust IP/LP section paired with a direct contact condenser. This top and axial exhaust arrangement proved successful on Zorlu's Alaşehir-1 plant and was carried forward to subsequent projects. Additionally, successful test results from the new wells during the early design phase of the project prompted an increase in the project size to 100 MW from the initial 80 MW.

Another design feature that was incorporated after successful implementation at the Alaşehir-1 project was the use of binary condensate for building heating. Hot condensate exiting the binary unit preheaters is used in building HVAC closed-loop heat exchangers to provide heating during the winter months.

3.4 Kızıldere-3 Unit 2 (KZD-3U2)

Less than six months into the design of the first unit of Kızıldere-3, planning for a second nearby plant began to pick up momentum. Such a swift progression of large design efforts required close coordination and sharing of resources between the development group and engineering teams. In order to take advantage of existing permits including EIA Positive Decision and implementation plan, interconnect agreements and common facilities, the new plant was located on land purchased for the first plant and the two units were designated Unit 1 and Unit 2. While placing Unit 2 under existing licensing agreements allowed design to begin right away, a much-shortened development cycle was required to get the plant commercial soon after Unit 1. Equipment suppliers, design engineers and commissioning teams were all tapped to manage the design and construction of both Units simultaneously.

One strategy employed by Zorlu to achieve this fast-track schedule was to maximize the common elements between the two units. The satellite separation station that was developed for Unit 1 was expanded to also serve Unit 2 and cross-country pipelines in the resource gathering system were upsized to account for increased flow. Other plant facilities, such as firewater, raw/potable water, control room, warehouses and switchyard were also modified to support two plants.

Zorlu also began to develop an interconnected resource gathering system between the new and old plants. Prior to KZD-3U2, each operating plant was essentially standalone in its operation. The addition of Unit 2 added interconnects not only with Unit 1 production and injection systems, but with the KZD-2 injection system as well. Interconnected injection systems have helped manage reinjection temperature, flow and chemical treatment at each well by distributing lower temperature flows across more wells and improved matching of flow to individual well injection capacity. Shared production systems allow Zorlu to shift geofluid between the new units and tune each for better resource efficiency. On a larger scale, the combined resources for KZD-2 and KZD-3 can be balanced to reduce bottlenecking and will be useful in minimizing generation reductions during periodic unit outages.

4. Drilling Overview

During the thirty-year exploration and development period between 1968 and 1998, twenty-two (22) wells were drilled at a depth ranging from 272 m to 2000 m. All but one of these wells terminated in the first or second reservoir, which are both shallower and thinner than the deepest reservoir. The last well drilled during this period was the first reinjection well at the site, R-1, and was placed in the third reservoir with the deepest production zone to date. This well was later turned into a production well during the Kızıldere-2 project. While some of the original wells are no longer in service, many of them continue to produce thanks to the rehabilitation effort and inhibitor systems installed in the early phases of the Kızıldere-1 project. The remaining out-of-service wells still provide useful data as observation wells to study and track the interference and interconnection of the field.

In the years since the 2008 acquisition, drilling activities across the field have picked up pace dramatically. As of 2018, Zorlu has a total of 42 production and 28 injection wells in service at the Kızıldere field. Table 3 shows the drilling progress of the wellfield through each phase of development and expansion of the field. The original plant did not have provisions for injection but this was rectified during the Kızıldere-2 expansion by sharing reinjection wells between the new and old plants. With almost as many injection wells as production wells in the new projects, Zorlu has stayed committed to the early goal of establishing a sustainable injection program at Kızıldere.

Table 3: Wells in service by project phase.

PLANTS OPERATING	PRODUCTION	INJECTION	PROJECT GROSS MW
Kızıldere-1	7	Common injection utilized (28)	15
+Kızıldere-2	11		80
+Kızıldere-3U1	14		100
+Kızıldere-3U2	10		65
+*Future*	*12*	*12*	*50-75*
TOTAL	54	40	260+

5. Human Capacity, Relationships and Zorlu's Development Workflow

Prior to 2008, Zorlu Energy was operating a portfolio of thermal and renewable plants for both industrial and power generation uses. The acquisition and operation of Kızıldere-1 provided a strong base from which Zorlu has grown their geothermal expertise. Their first geothermal plant could have been considered a "training ground" for new and existing staff to get up to speed on unique aspects of geothermal operations. The resource and operations staff they inherited has helped form an experienced technical team that has mentored newcomers and taken on new managerial roles within the group. For a new developer interested in later expansion, acquiring an existing asset (even if distressed) with a solid operations team may have benefits far beyond the balance sheet one might examine during due diligence.

The Kızıldere-2 project accelerated the development of human capital within Zorlu's development and construction teams. As Kızıldere-1 built the foundations of the operations staff and resource group, so did the planning, construction and commissioning of Kızıldere-2 help lay the foundations for execution of future projects by in-house talent. During the planning and design stages of Kızıldere-3 Units 1 and 2, Zorlu provided more input to the design specifications, plant layout and preferred plant features after experiences gained during design and operation of Kızıldere-2.

Indicative sizes of Zorlu's different teams over time for development, construction management and operations of these various projects are shown in Table 4. As Zorlu continues to grow, these groups must be continually augmented by new engineers and technicians, for which a solid pipeline of qualified candidates from Turkish institutions is essential. The partnerships formed with these institutions over the years provides many opportunities for students, professors and engineers to work together and exchange knowledge. Not shown is the increasing staff involved in the drilling operations.

Table 4: Staff growth over time by group.

PLANTS OPERATING	END YEAR/PROJECT	DEVELOPMENT GROUP	CONSTRUCTION GROUP	OPERATIONS GROUP
Kızıldere-1	2008	5	N/A	14
Kızıldere-2	2013	16	45	42
Kızıldere-3U1	2017	38	64	82
Kizildere-3U2	2018	40	67	84

The spread of knowledge can also be observed in the growth of local industries. Chemical injection systems and inhibitors were first used in this field right after the privatization with the contribution of Zorlu Energy. These test studies led some of the local Turkish manufacturers and suppliers to develop their own products and chemical inhibitors for the geothermal market. It also helped many academicians and operators to harvest data on the geochemistry of the geothermal fluids and better understand available treatment options.

All operations and maintenance (O&M) activities are done by Zorlu's dedicated O&M team internally. This benefits local employment and capacity building in high-skilled technical fields, and with this buildup of human capital, Zorlu is capable of providing service for other geothermal institutions with its experienced and dedicated team members.

6. Future Projects

With the future of the geothermal feed-in tariff uncertain, new development has been primarily focused on projects that can be completed prior to the expiration of current rates in 2020. To that end, Zorlu currently has several projects in early development phases across their various concessions and aims to have those complete prior to the deadline. Kızıldere-4 and Tekkehamam, both located within the Kızıldere field, will benefit from the knowledge and experience the Zorlu team has gained over the last ten years of development in this region. Another project planned to be commissioned by 2020 is Alaşehir-2, 4 kilometers away from the existing 45 MWe Alaşehir-1 geothermal power plant.

While new development gets the headlines, smaller rehabilitation projects are instrumental to maintaining plant output and resource longevity. Some such projects under consideration for the existing plants include improving injection capacity, adding supplementary injection and increasing interconnection of the different resource gathering systems for enhanced production and balancing of flows. Also under consideration are expanding the current CO_2 capture and greenhouse heating programs, as well as creating a geothermal learning center and thermal spas, as methods of increasing community interaction and benefit.

Zorlu and METU (Middle East Technical University) have been awarded a project by the Turkish Scientific and Technological Research Council of Turkey (TÜBİTAK) to study the topic of “Enhanced Geothermal Systems-Reinjection and Storage of CO_2.” Together they will try to reinject liquid CO_2 into the reservoir to observe the effects of CO_2 reinjection on the system and productivity of the field. There are also two (2) different Horizon2020 applications to the European Commission conducted by Zorlu with the contribution of at least fifteen partners from different countries. One project is about reducing the carbon emissions while the other addresses thermal energy storage systems.

7. Conclusions

With the rapid growth of the Turkish geothermal market in the last decade, sustainable reservoir development and management practices are important for current and future developers to help extend the lifetime of the natural resources. The expansion in Zorlu’s Kızıldere geothermal concession area has been successful in part due to its established resource management and development group, as well as a commitment to sustainable growth. The development of human capital and internal resources has resulted in a ten-fold increase in team size. New facilities that utilize advances in geothermal combined cycle technology, district heating and CO_2 emissions reductions have brought Zorlu to the vanguard of the pack in a competitive market. The addition of community oriented projects, integration with local businesses and job creation have helped Kızıldere contribute to the region’s economic success. As the field continues to grow and mature, the steps that have been taken over the last decade will help guide the next generation of plants and personnel to maintain a valuable local resource.

REFERENCES

Energy Markey Regulatory Authority (EMRA). 2018. 2018 Yılı Nihai YEK Listesi. <http://www.epdk.org.tr/Detay/Icerik/3-0-72/elektrikyekdem>. Accessed 2018 May.

Kindap A, Kaya T, Tut F. 2009. Privatization of Kizildere geothermal plant and current approaches for the field and plant. GRC Transactions, Vol. 33, 2009.

Lewis W, Wallace K, Dunford T, Harvey W. 2015. Kizildere II multiple-flash combined cycle: a novel approach for a Turkish resource. Proceedings of the World Geothermal Congress. Melbourne, Australia, 19-25 April 2015.

Richter A. 2018. Turkey reaches milestone 1,100 MW of installed geothermal power generation capacity. < http://www.thinkgeoenergy.com/turkey-reaches-milestone-1100-mw-of-installed-geothermal-power-generation-capacity/>. Accessed 2018 May.

Tamaya Y, Muto T. 2014. Unique steam turbine for Kizildere geothermal power plant in Turkey. GRC Transactions, Vol. 38, 2014.